# Ben Franklin in the 21st Century

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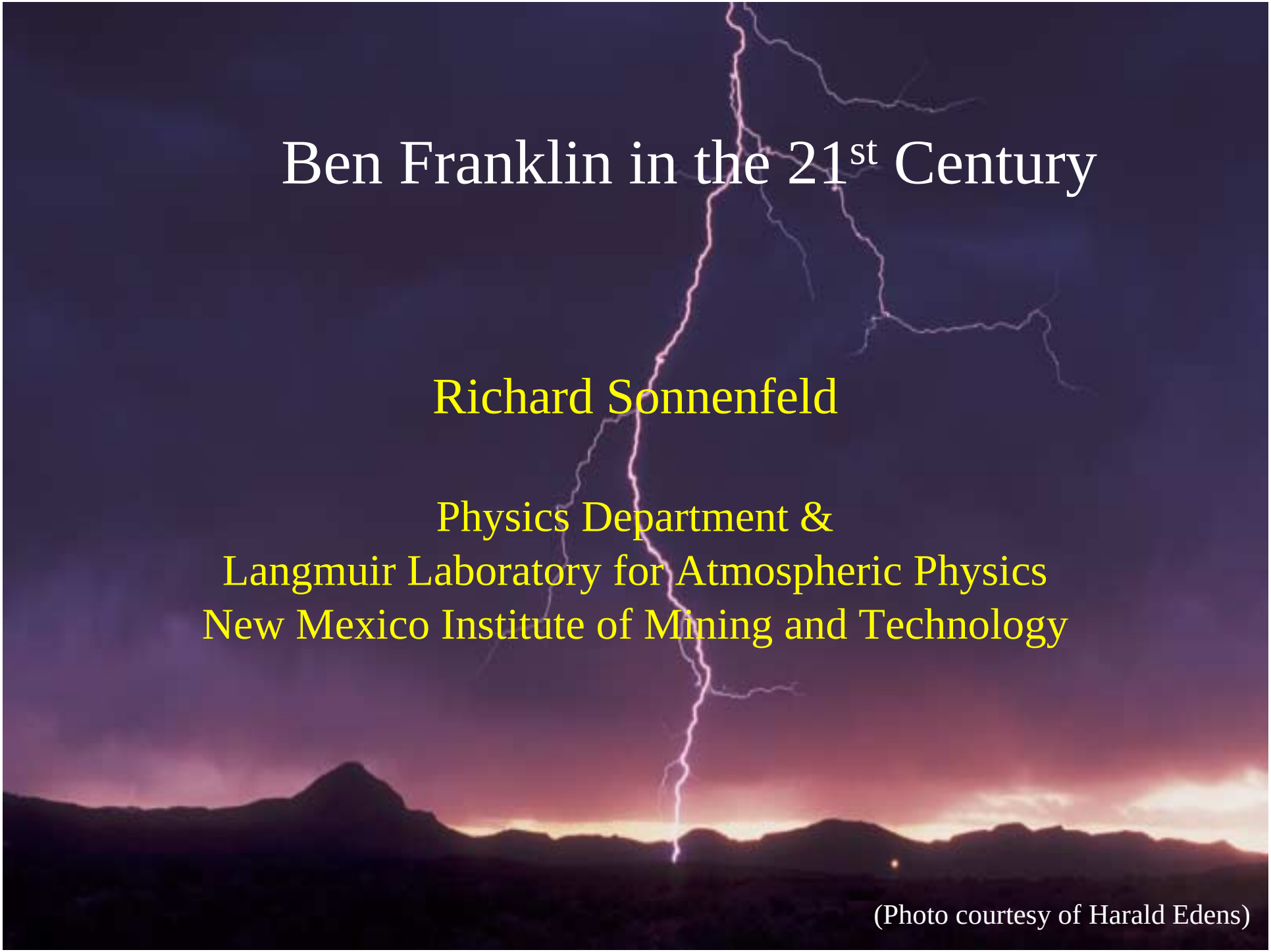


(Photo courtesy of Harald Edens)

# Lightning Effects

- Lightning kills approximately 100 people/year in US.
- Costs $4-5 Billion/yr in disrupted power lines, destroyed electronics.
- Lightning sets off ammunition dumps, fumes, and mine gasses.

# Lightning Research Products

- Understanding of lightning effects on climate change (N2O production)
- Improved lightning rods
- Lightning resistant aircraft
- Lightning warning systems / tornado warnings?
- Global lightning location networks

# Outline

- Franklin's contributions
- How a lightning flash develops, streamers and leaders and attachment.
- Lightning rods.
- Electrical definitions
- Electric field studies of lightning
- The lightning mapping array (LMA)
- Operational Meteorology and Climatology
  - Lightning and convection
  - The national lightning detection network
  - The LMA and severe storms
  - Space studies.

# Franklin's contributions to lightning science

- Lightning is an electrical phenomenon, governed by the same principles as laboratory static electricity.
- Most lightning strokes carry negative charge to ground, though some move positive charge to ground.
- A noticeable electric field is produced under an active storm.

(Photo courtesy of Harald Edens)

# Lightning facts we know now

- 40 flashes/second on Earth.
- Peak current I=100,000 Amps
- Voltage V=100 Million Volts
- Charge transfer Q=20 Coulombs
- Energy E= 1 billion joules

  (300 kWatt-hours)
- Channel radius r=1 cm
- Stepped Leader velocity 0.001c
- Dart Leader velocity 0.1c
- Return Stroke velocity  0.5c

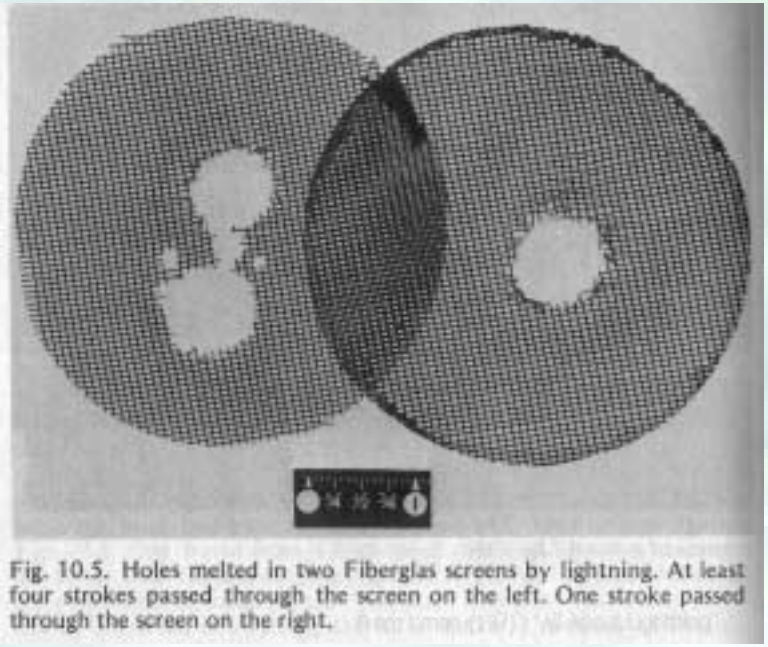


Fig. 10.5. Holes melted in two Fiberglas screens by lightning. At least four strokes passed through the screen on the left. One stroke passed through the screen on the right.

(From Uman, “All About Lightning “-- 1971)

# Benjamin Franklin and the Sentry Box Experiment

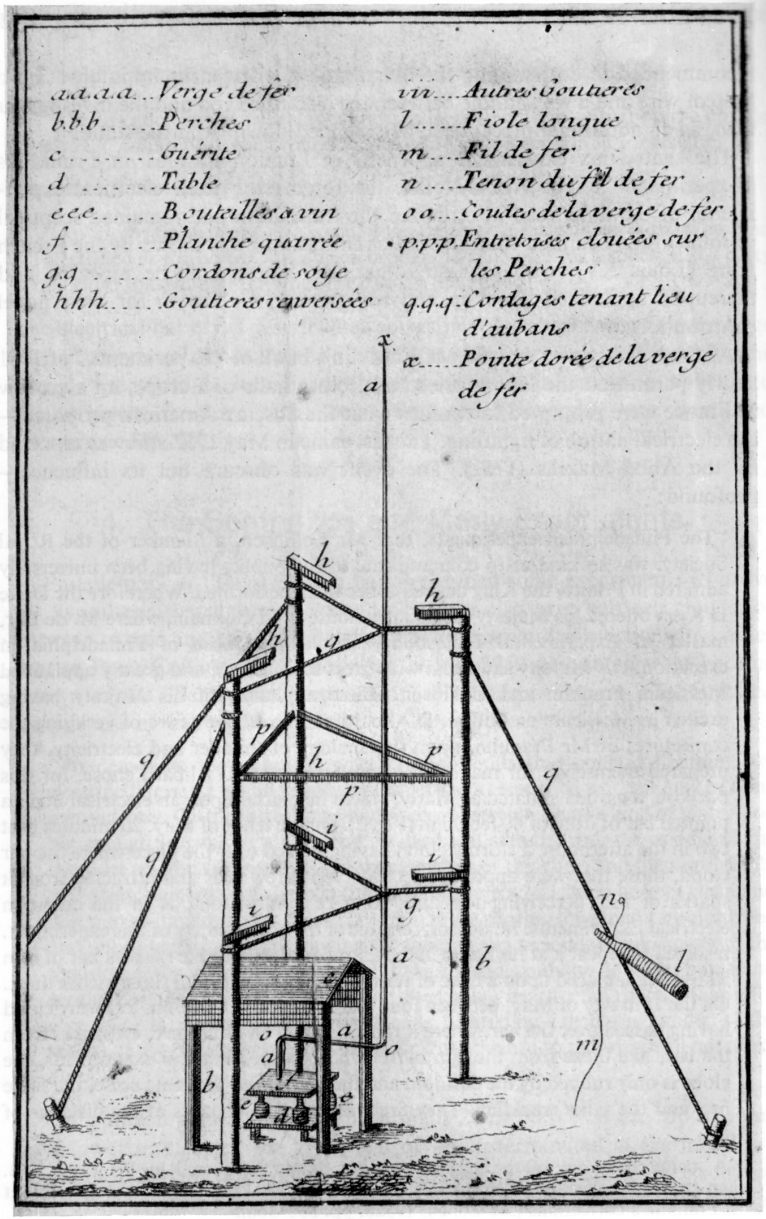
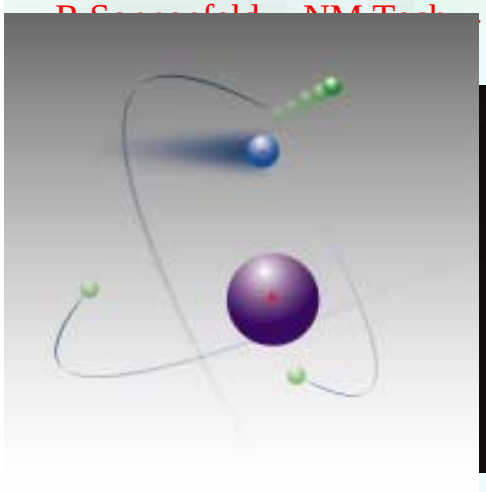



Fig. 2. Experimenters who had read the French translation of Franklin's book on electricity erected a 40-ft lightning rod at Marly, near Paris. On 10 May 1752 storm clouds gathered, and sparks were drawn by two attendants.

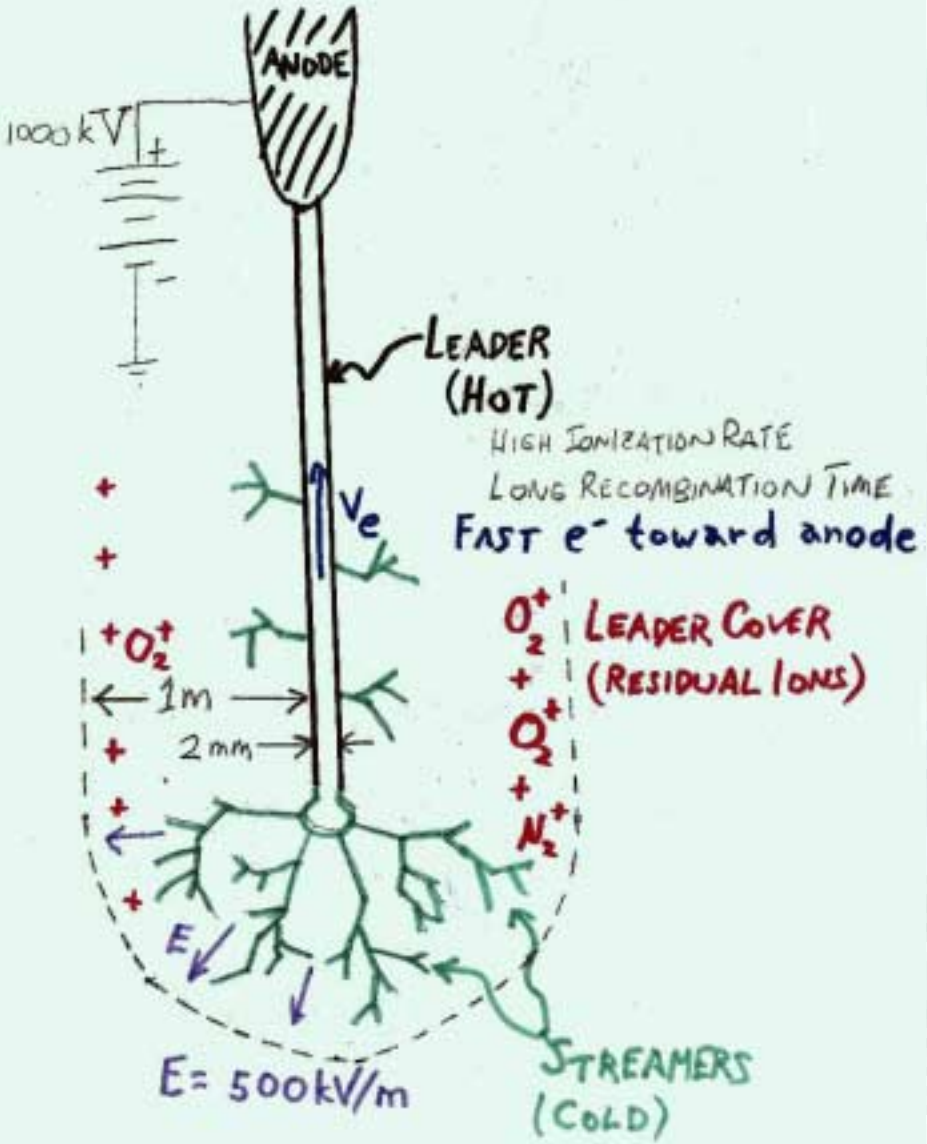


Impact Ionization
(From cosmicray.bnl.gov)

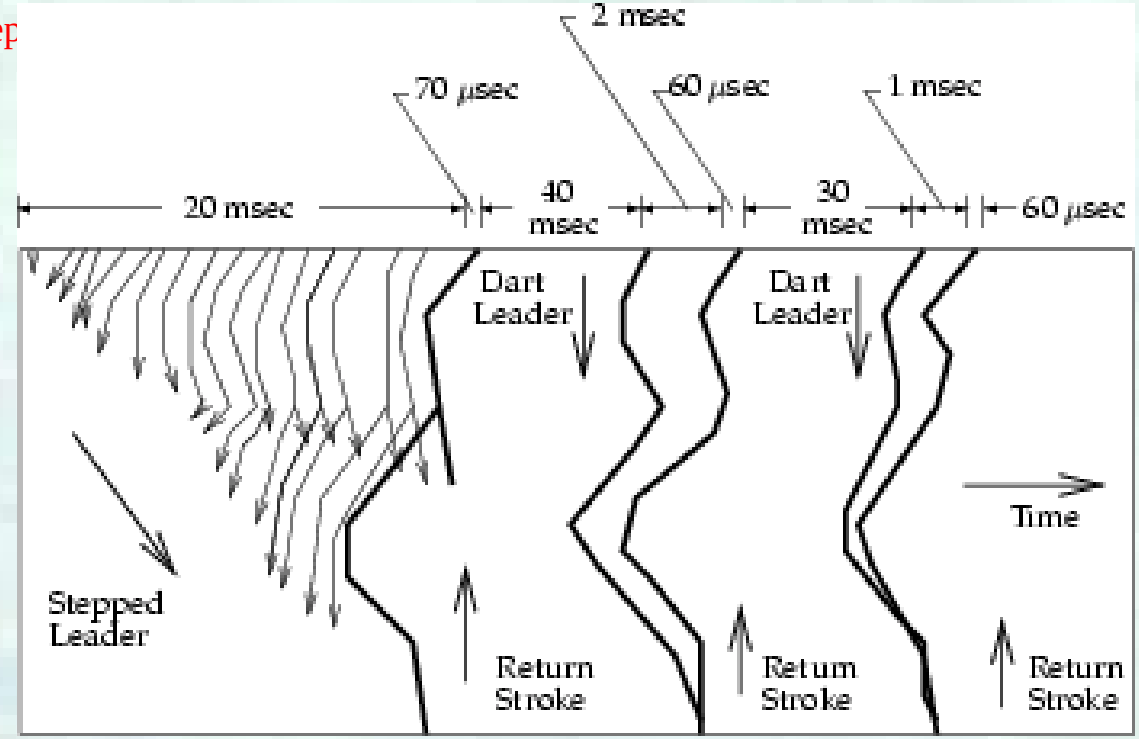
Corona Discharge
(Courtesy of H. Edens)

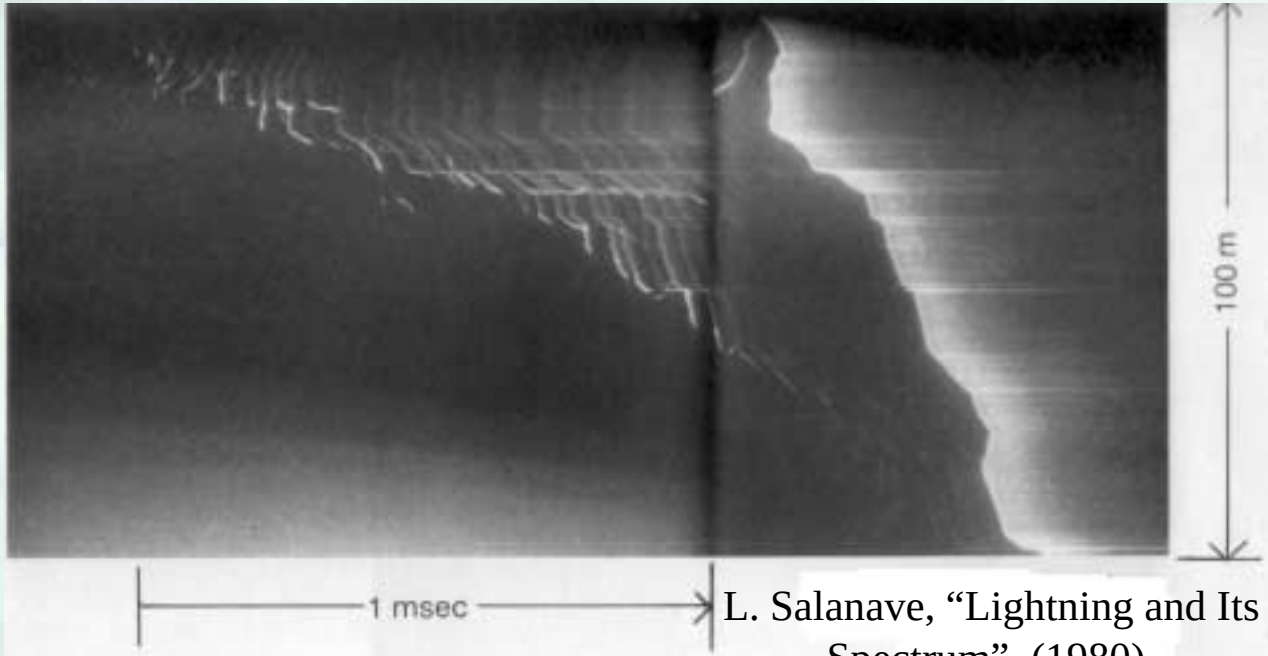
Streamers
(Courtesy of J. Kronjaeger)

## Leaders and Streamers



# Streak Camera Photography


L. Salanave, "Lightning and Its Spectrum", (1980).

# Lightning Launched Upward from Structures

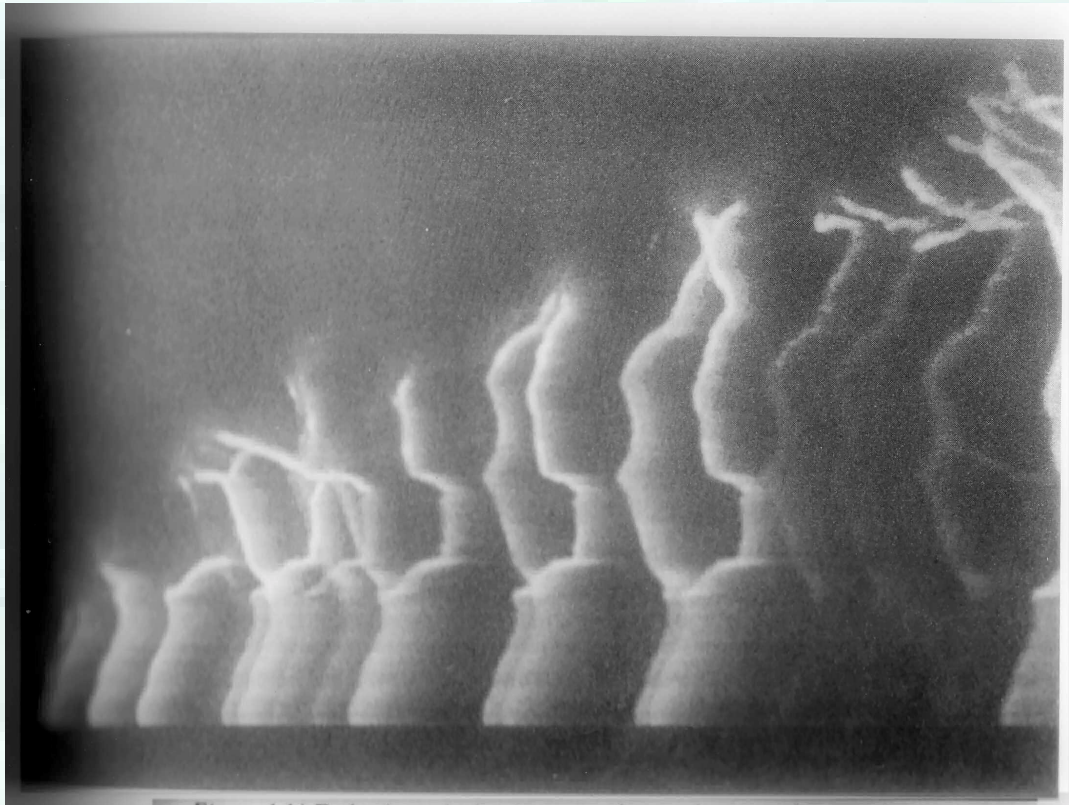
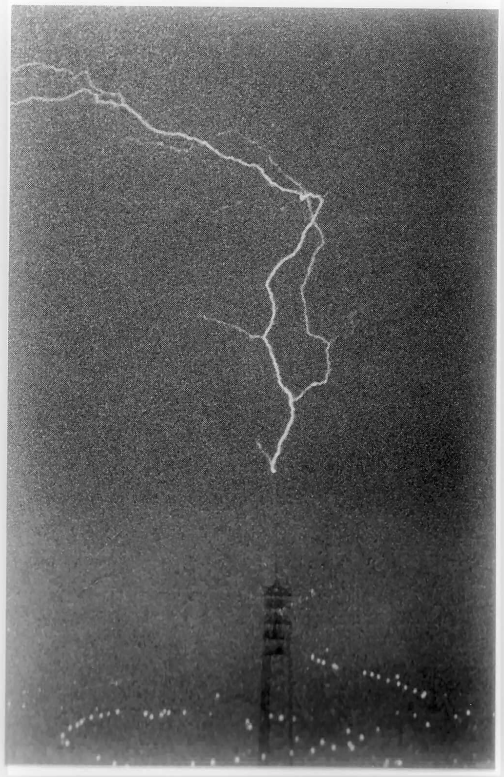
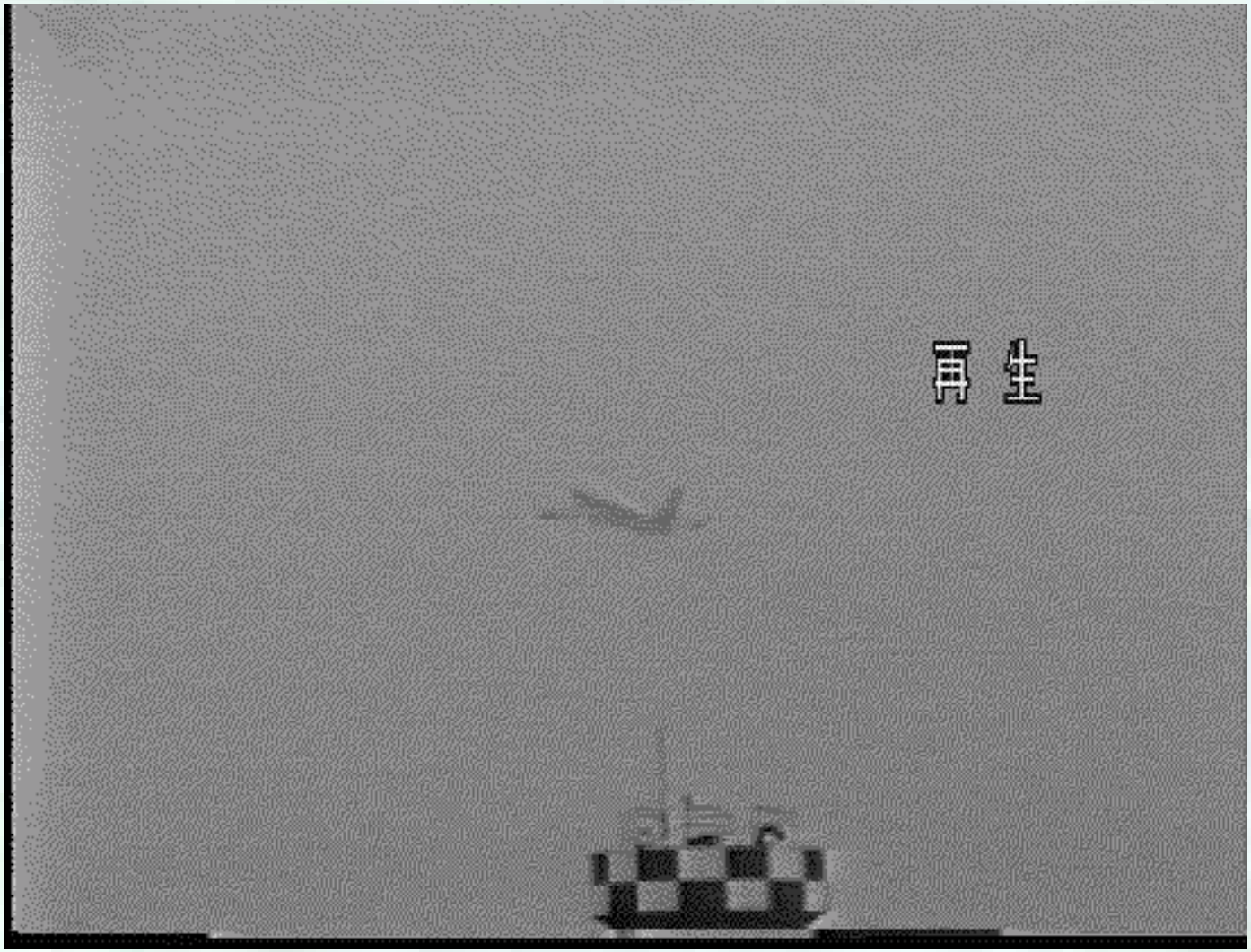


*Figure 4.14* Early phases in development of upward propagating negative leader

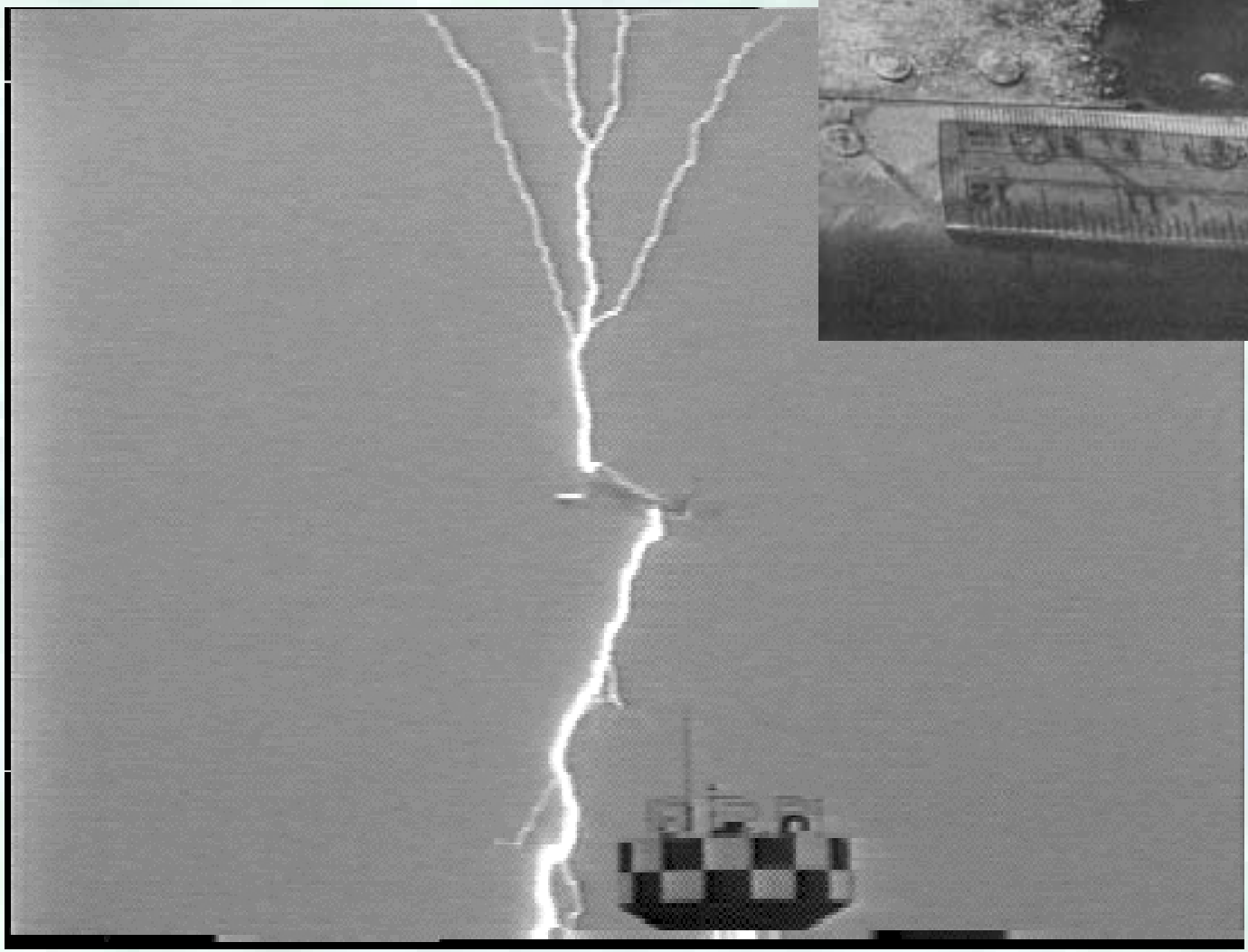


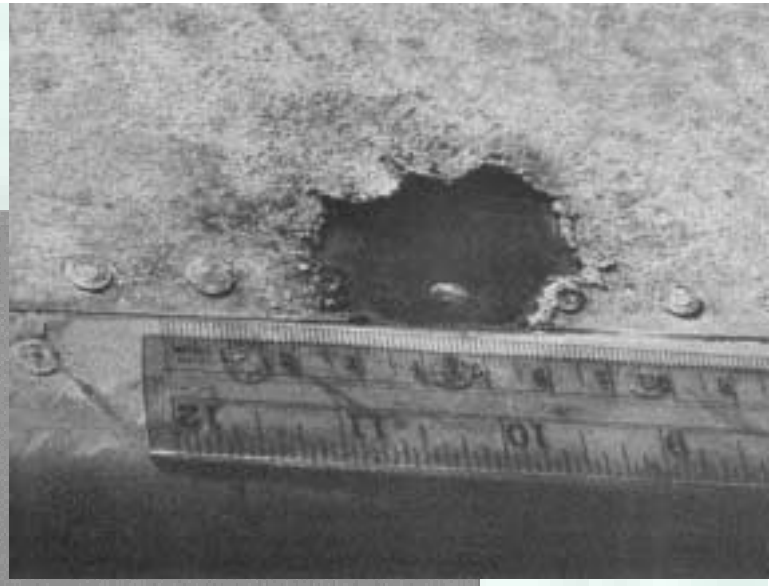
From: L. Salanave, “Lightning and Its Spectrum”, Univ. of Arizona Press, (1980).

# Triggered Lightning (Unintentional)




Aircraft at Kamatsu Air Force Base (Courtesy of Prof. Zen Kawasaki).





Commercial aircraft at Kamatsu Air Force Base (Courtesy of Prof. Zen Kawasaki).

# Lightning Rods

(Air terminals)

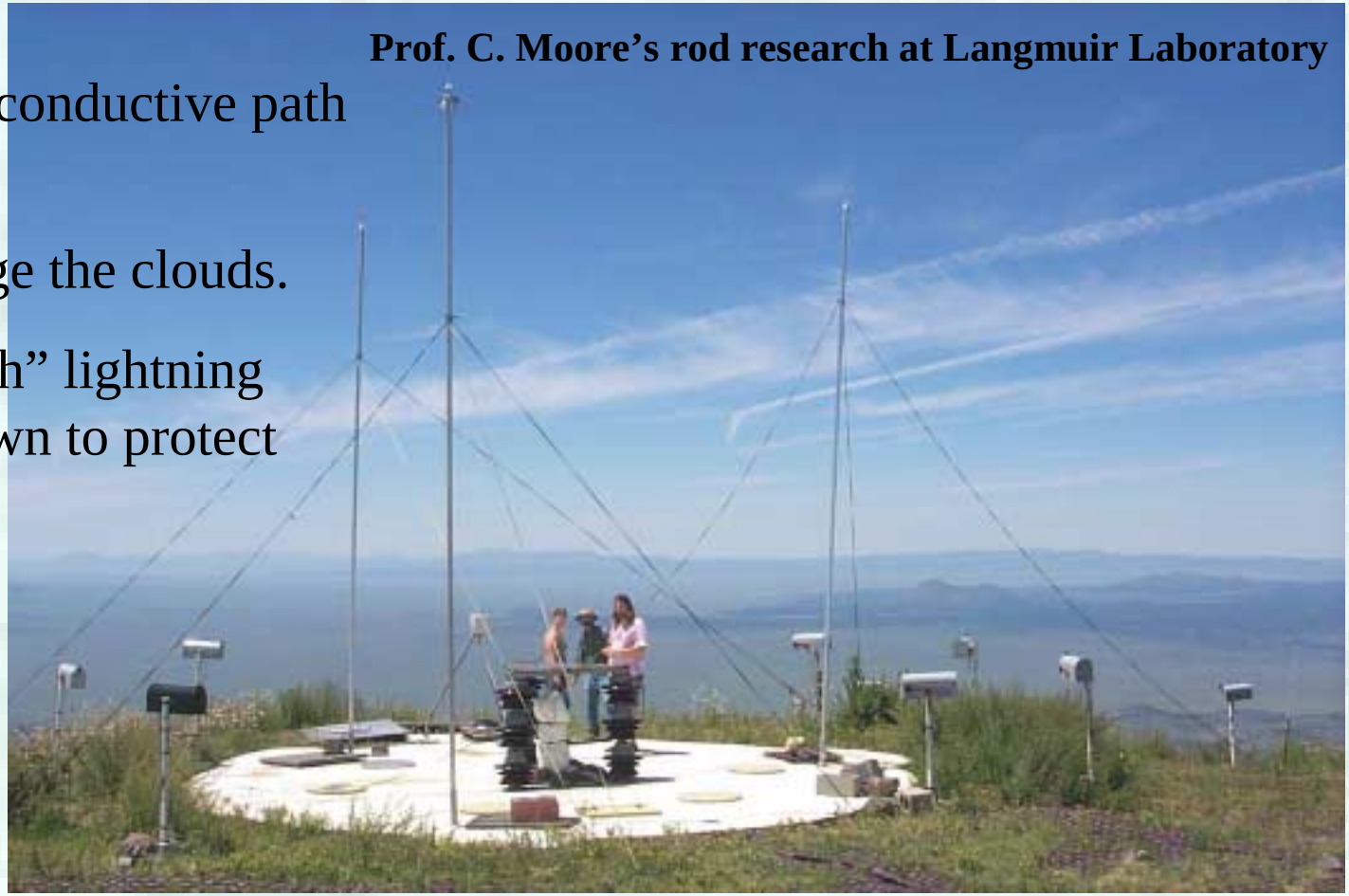
Offer small zone of protection (20 m radius rolling sphere—See NFPA 780).

Are preferentially hit if launch upward leader.

Provide a highly conductive path to ground.

Do NOT discharge the clouds.

No “Breakthrough” lightning rod has been shown to protect large areas.



**Prof. C. Moore’s rod research at Langmuir Laboratory**

# Lightning Connection Process

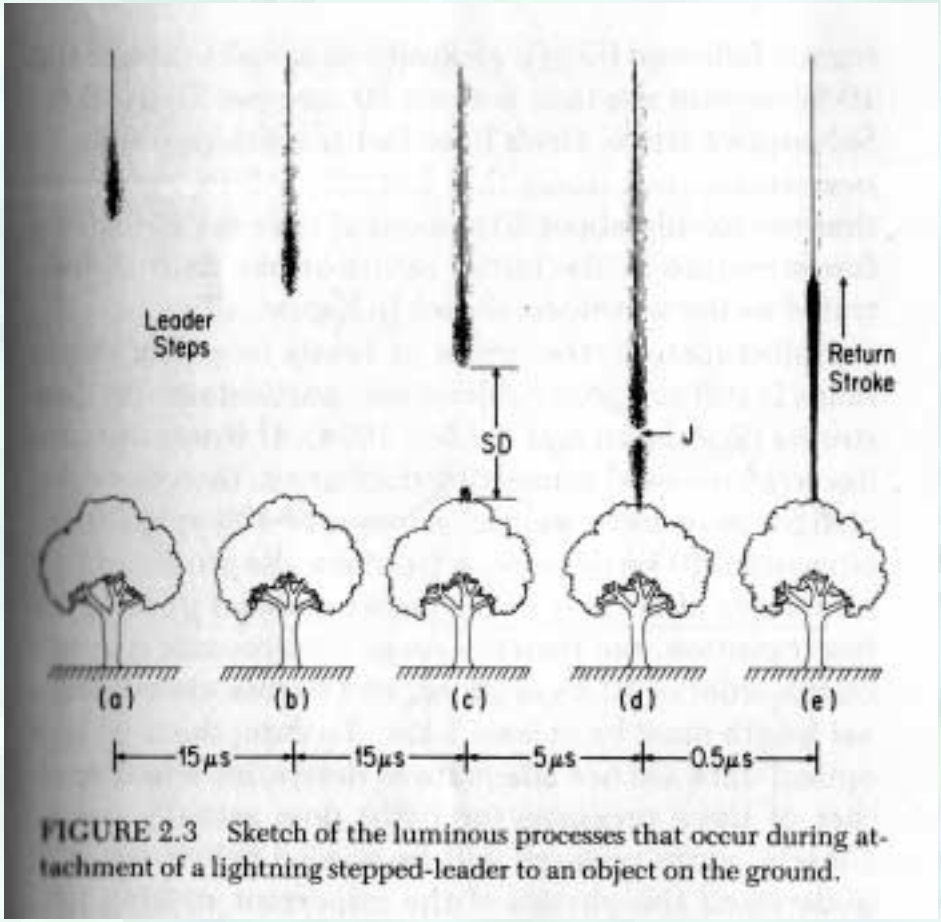
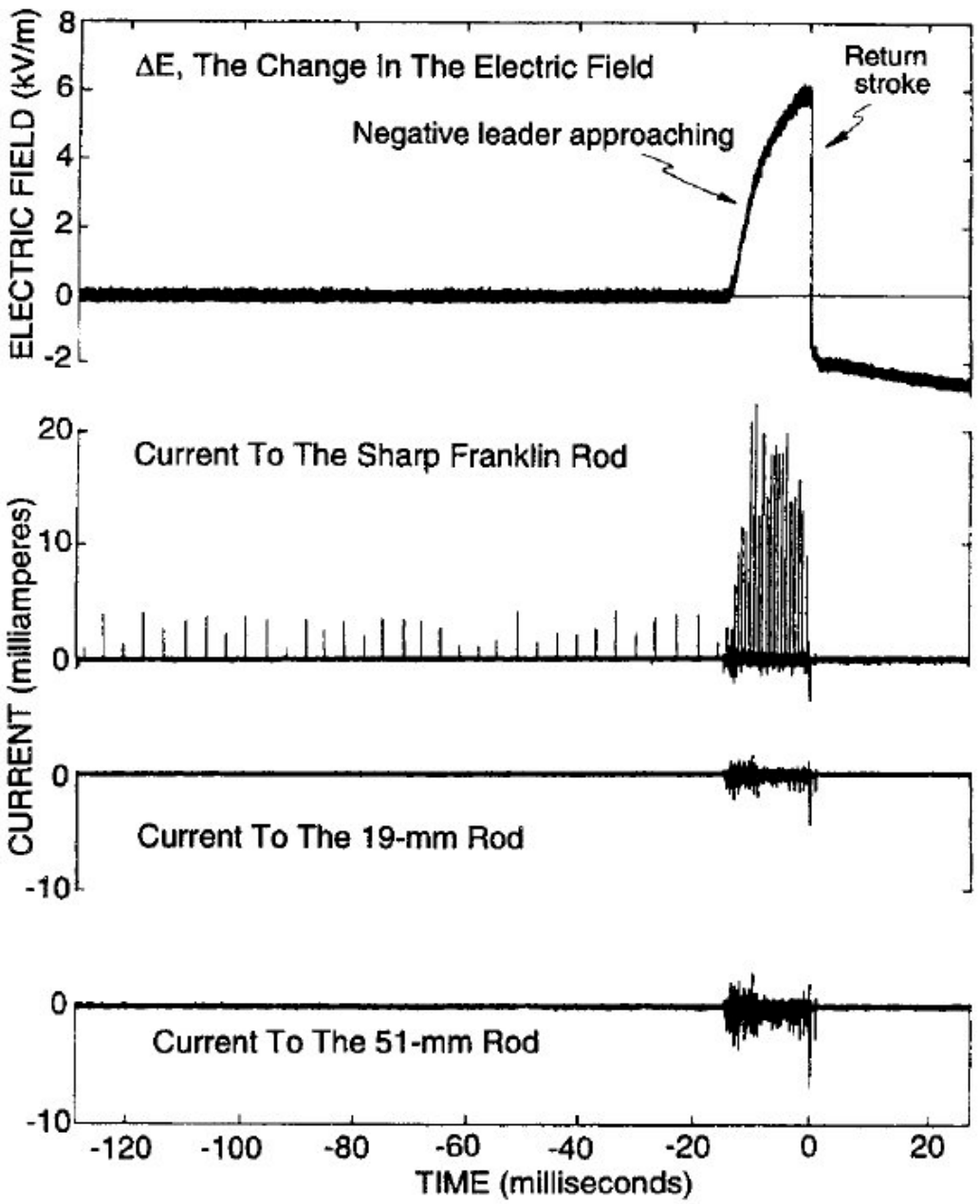



FIGURE 2.3 Sketch of the luminous processes that occur during attachment of a lightning stepped-leader to an object on the ground.

From: P. Krider, "Physics of Lightning", National Academy Press, (1986).

# Blunt vs. Sharp Rods




From Moore et. al, "Lightning Rod Improvement Studies" JAM, 39, (2000)

# Triggered Lightning

**Langmuir Laboratory lightning triggering experiment**

- Can be used to study lightning effects
- Bring the lightning to your home /airplane / computer / power plant.
- A grounded wire trails behind a rocket

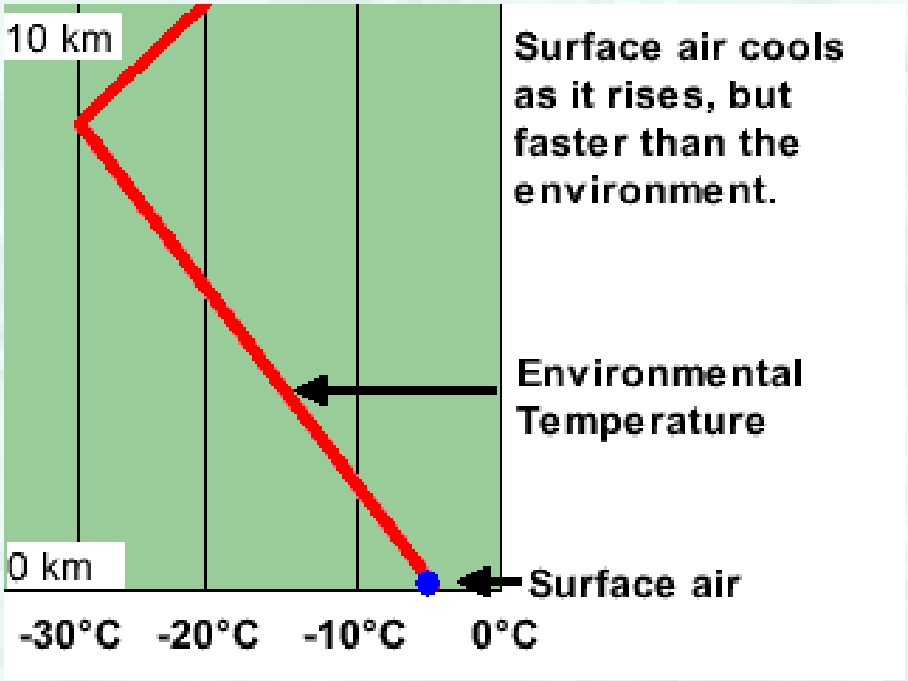
# Is lightning possible?
# Where does the energy come from?

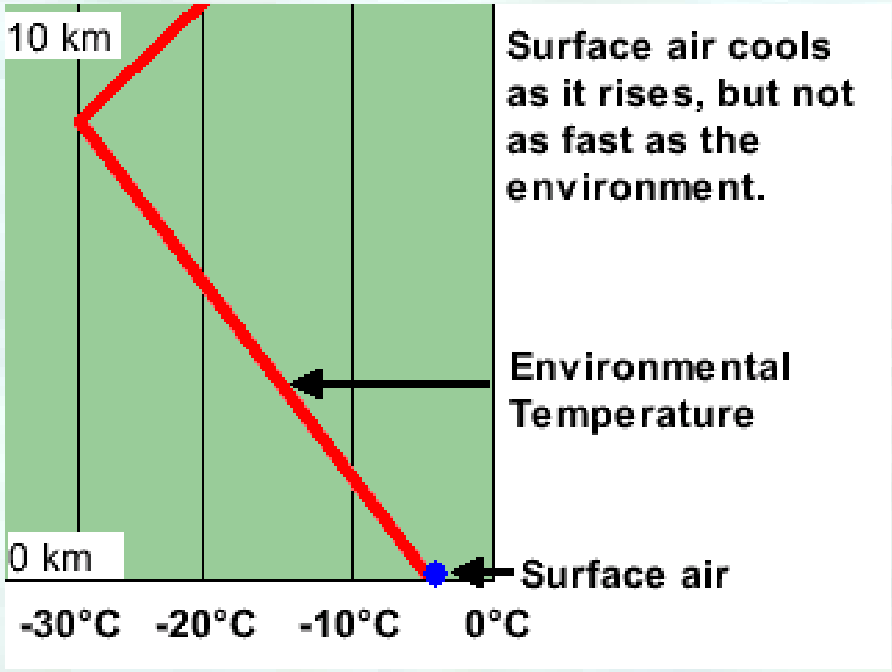
- Need 1 billion joules in 1 km^3 of air –

# Energy Source for Lightning (and weather!)

- Need 1 billion joules in 1 km^3 of air –
- Energy Source 1 -- Moisture
  - Moist air in New Mexico has 1 g of water vapor in 1 m^3
  - Heat of condensation of steam is 2300 kJ/kg
  - If all the vapor in 1 km^3 condensed, it would produce 2300 billion Joules (2300 GJ), enough for 2300 lightning strokes.
- Energy Source 2 -- Buoyancy
  - Hot air balloons use 100 C temperature difference to get lift.
  - Moist air becomes 2-3 C warmer than dry air as it rises.
  - It is 1% less dense than dry air.
  - 1 km x 1 km x 1 km that is 3 C warmer than surrounding has Buoyant Force=1.3E10 N*0.01=1.3E8 Newtons
  - Energy for 1 km ascent = 130 GJ – enough for 130 strokes.

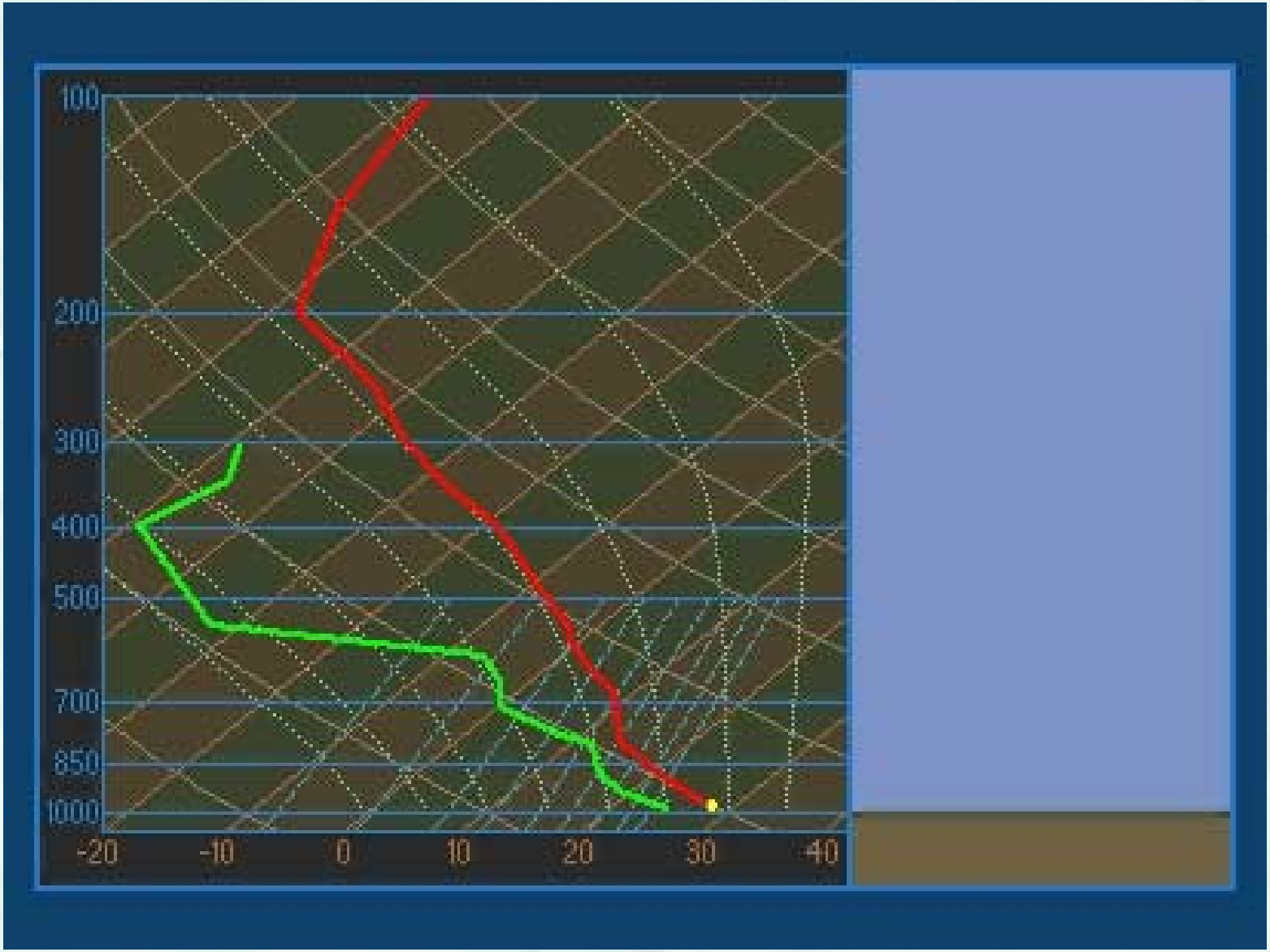
# Atmospheric Instability



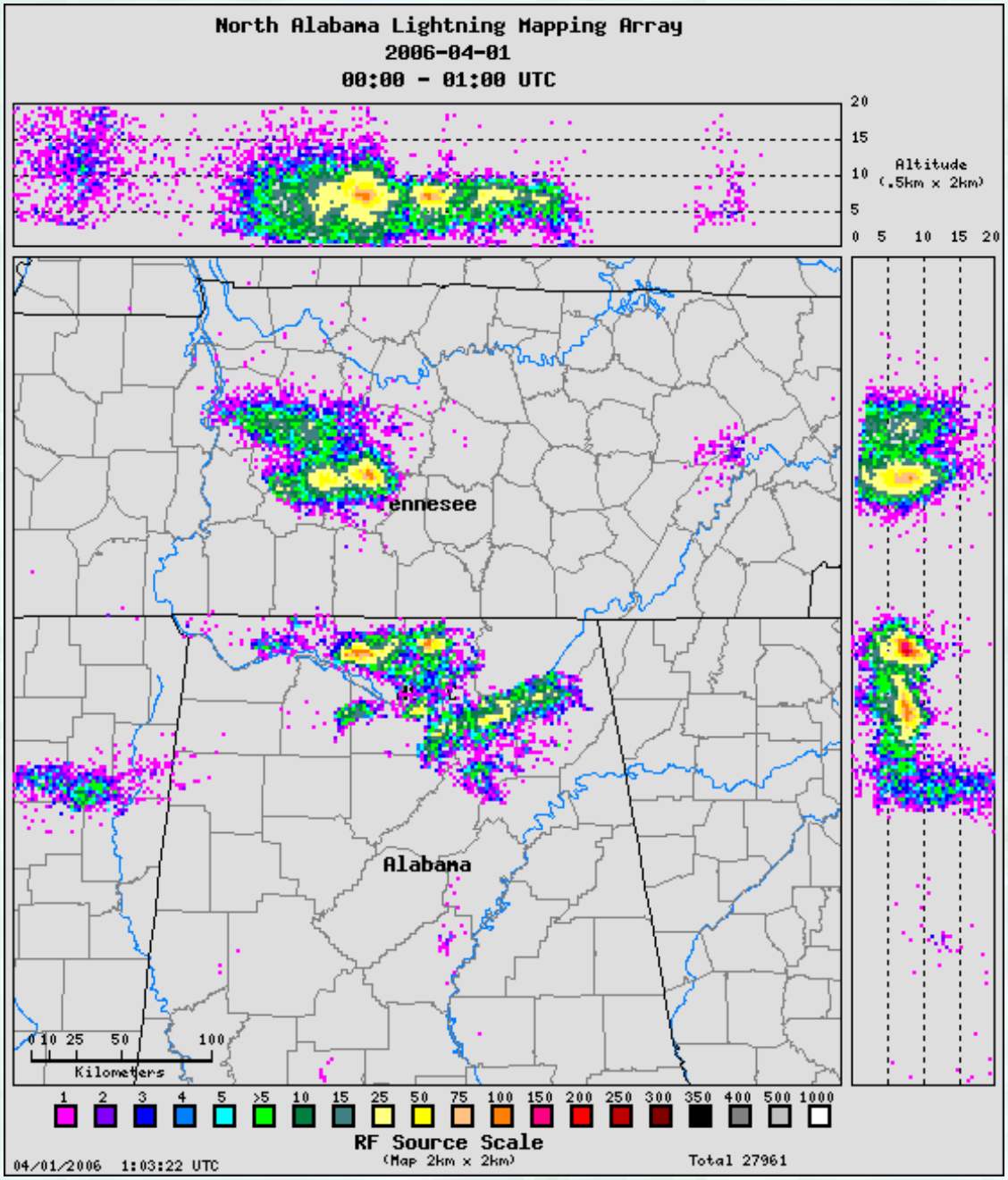




**From Weather2010 project, Univ. Illinois and Urbana-Champaign**

# Convective Available Potential Energy (CAPE)

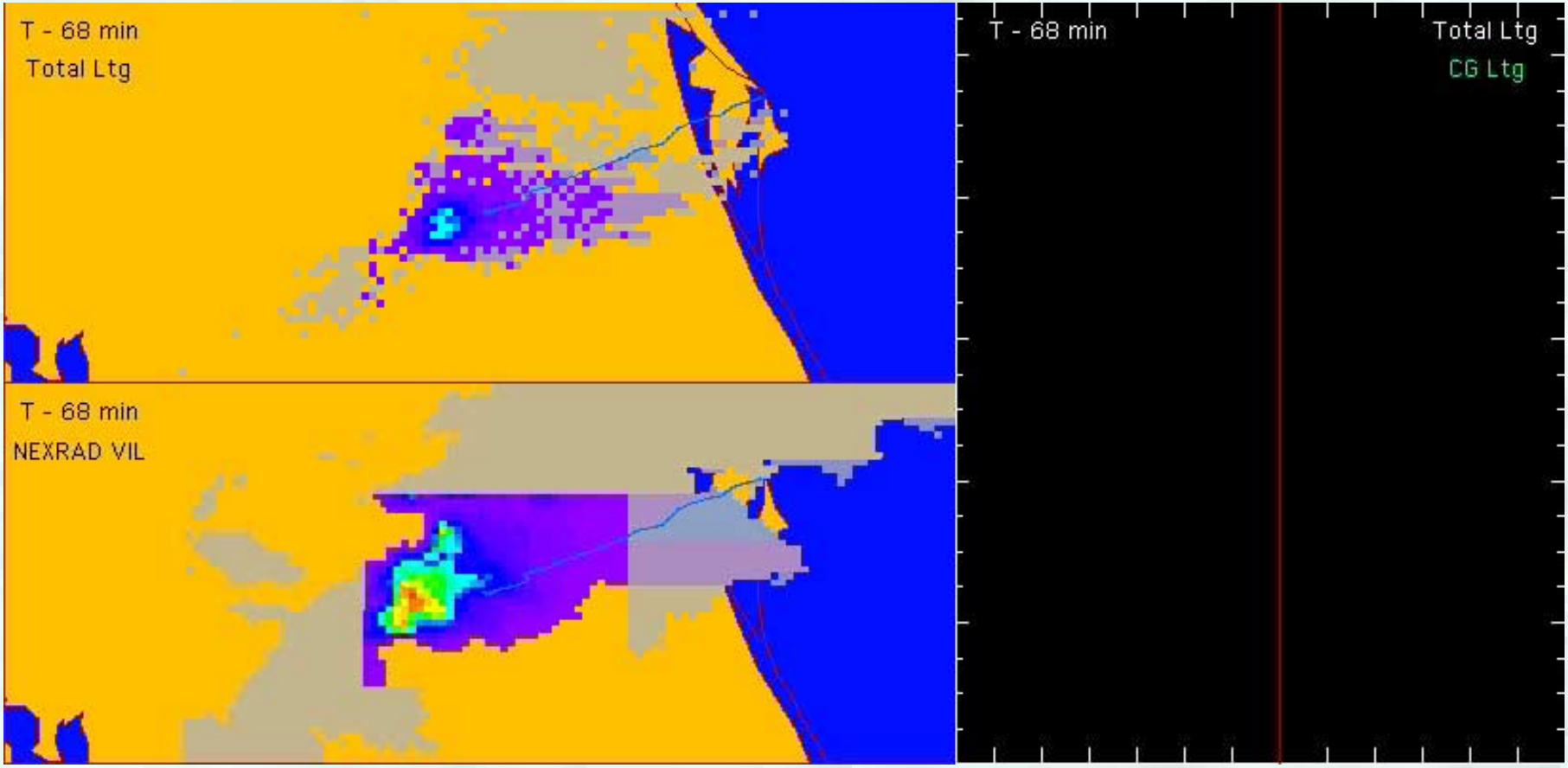



**From Weather2010 project, Univ. Illinois and Urbana-Champaign**




- So Lightning needs Water vapor, convection, and updrafts.
- Lightning likes SEVERE Weather!

# Tornado “Nowcasting” with the Alabama Lightning Mapping Array




Intra-cloud lightning peaks just before a tornado touches down.

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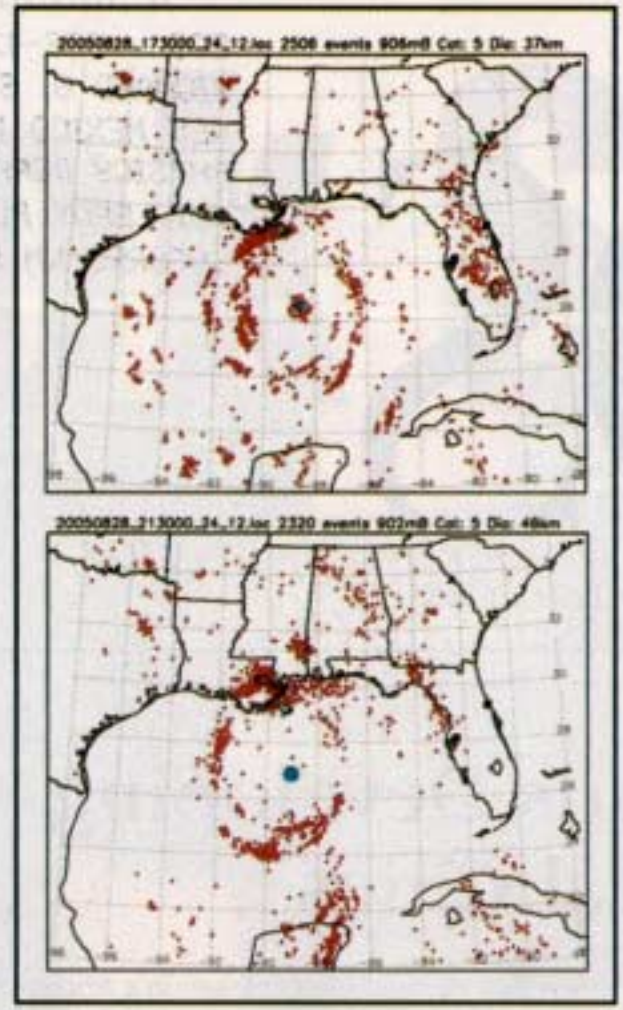


*Fig 1. Lightning observations of Hurricane Katrina. (top) Geolocated lightning events (red dots) during 1730:00–1930:00 UTC, 28 August 2005. (bottom) Lightning events during 2130:00–2330:00 on the same day. Blue discs show the position and size of the hurricane eye.*

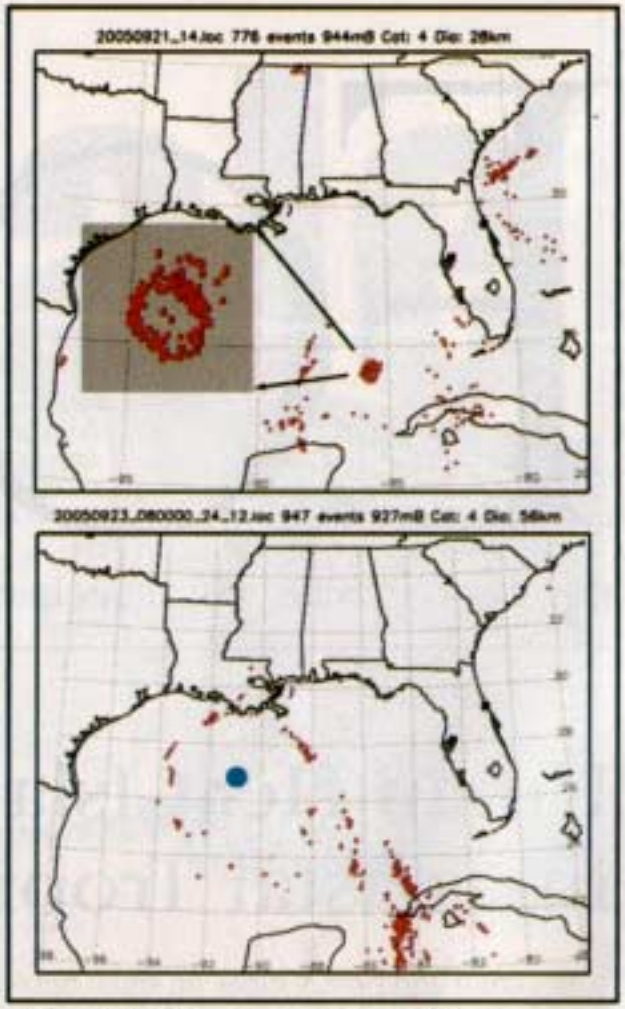
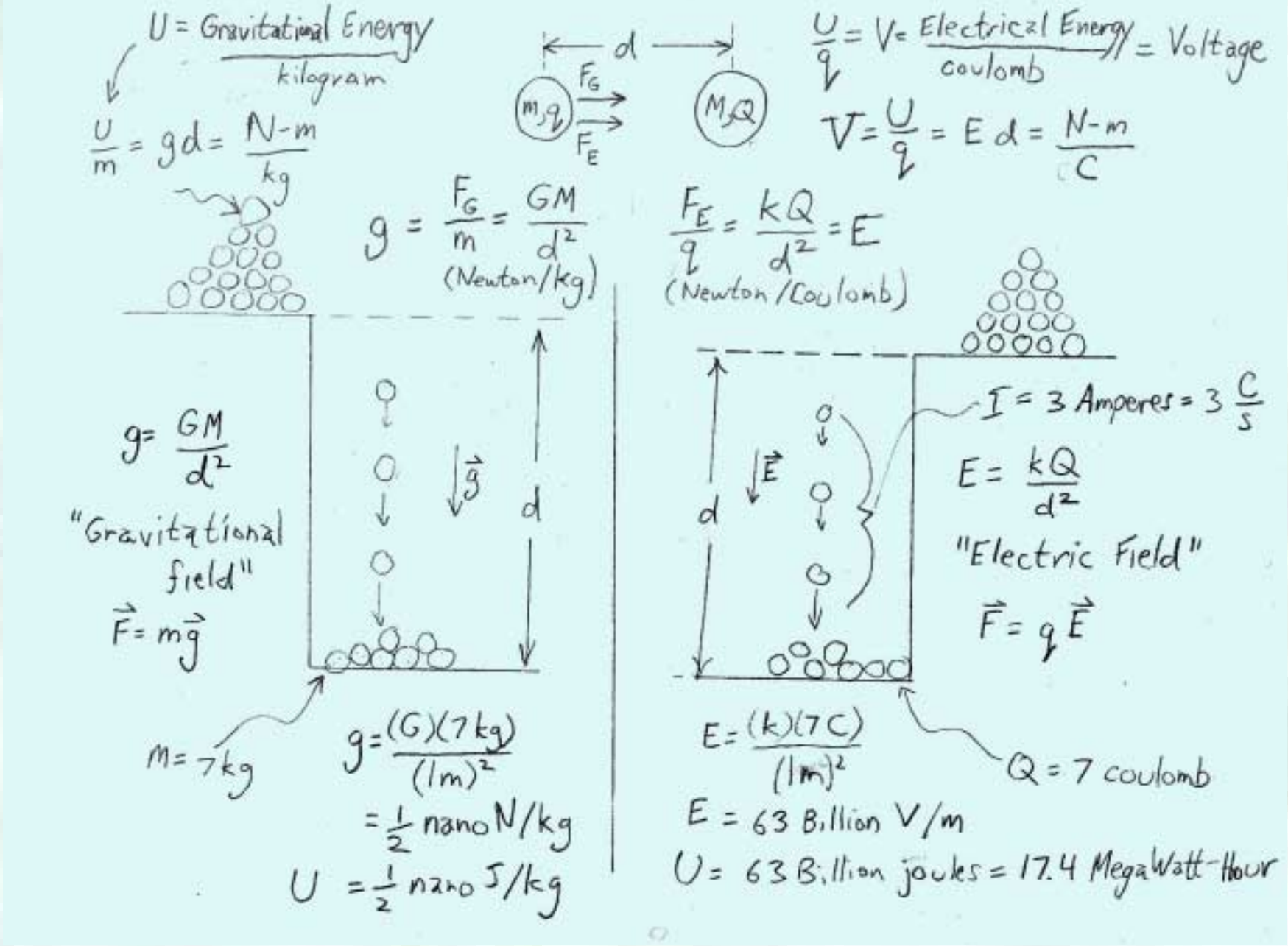


*Figure 2. Lightning observations of Hurricane Rita. (top) One hour of data from 1400:00–1500:00 UTC, 21 September 2005. (bottom) 0800:00–1000:00 UTC, 23 September 2005.*

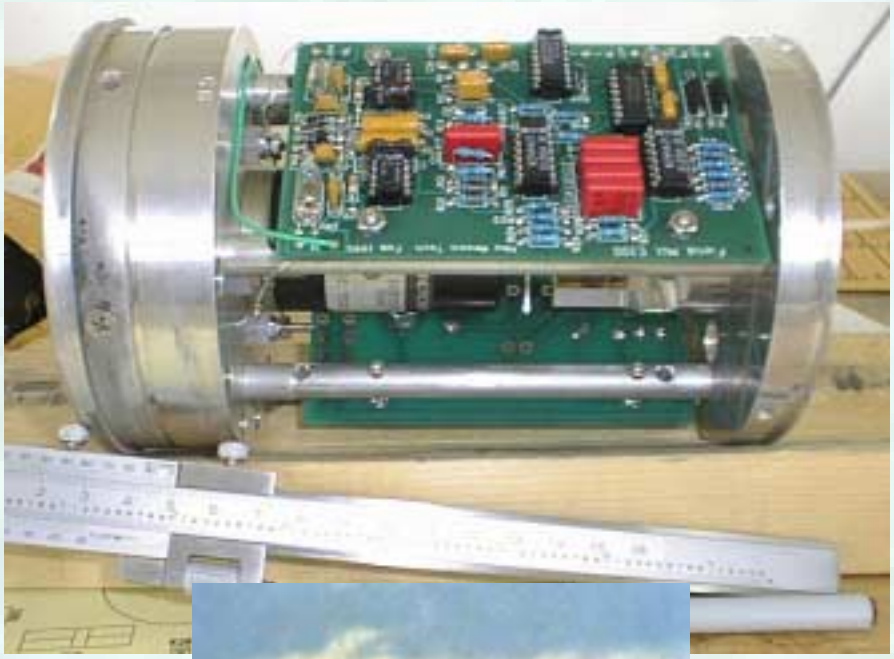
Lightning is associated with Hurricane Eyewall intensification

Data from "EOS" Newsletter of AGU. Work by Los Alamos lightning group. (X. Shao et al.)

# Analogy between Gravity and Static Electricity

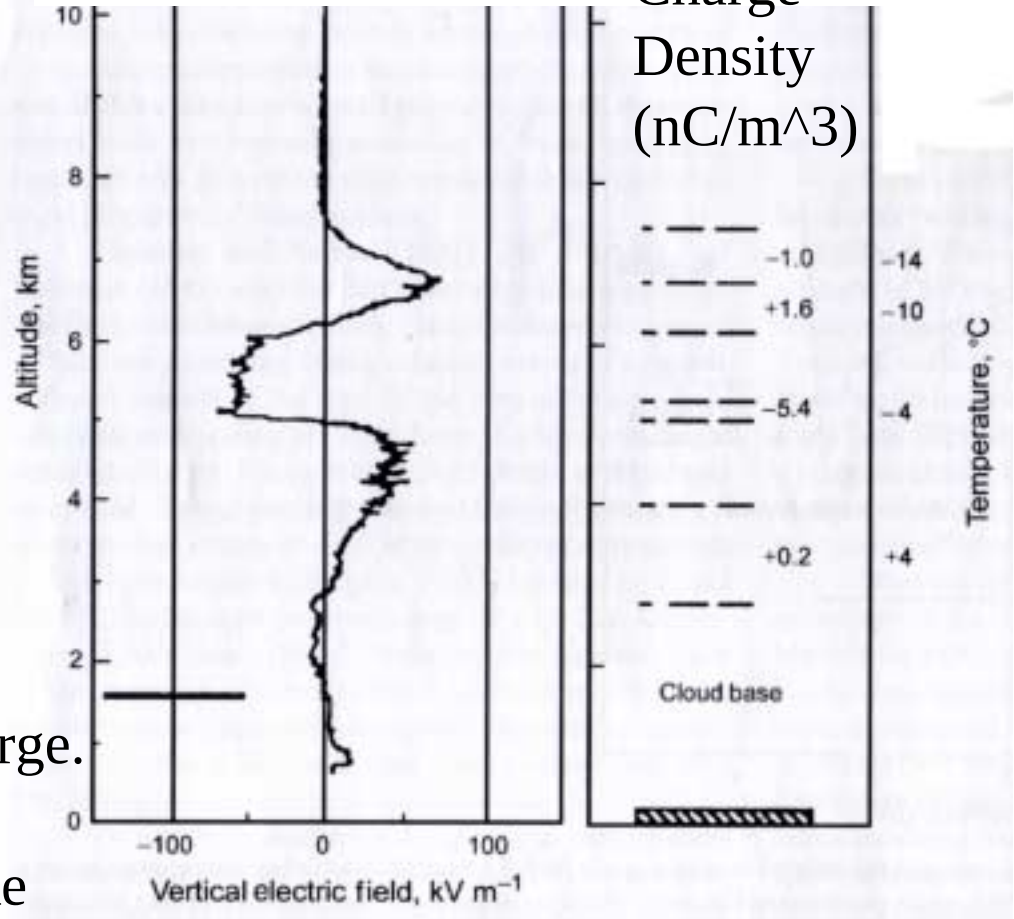


# Electric field detection



"E100" Field meter by Prof. W. Winn, New Mexico Tech

# How do storms electrify?

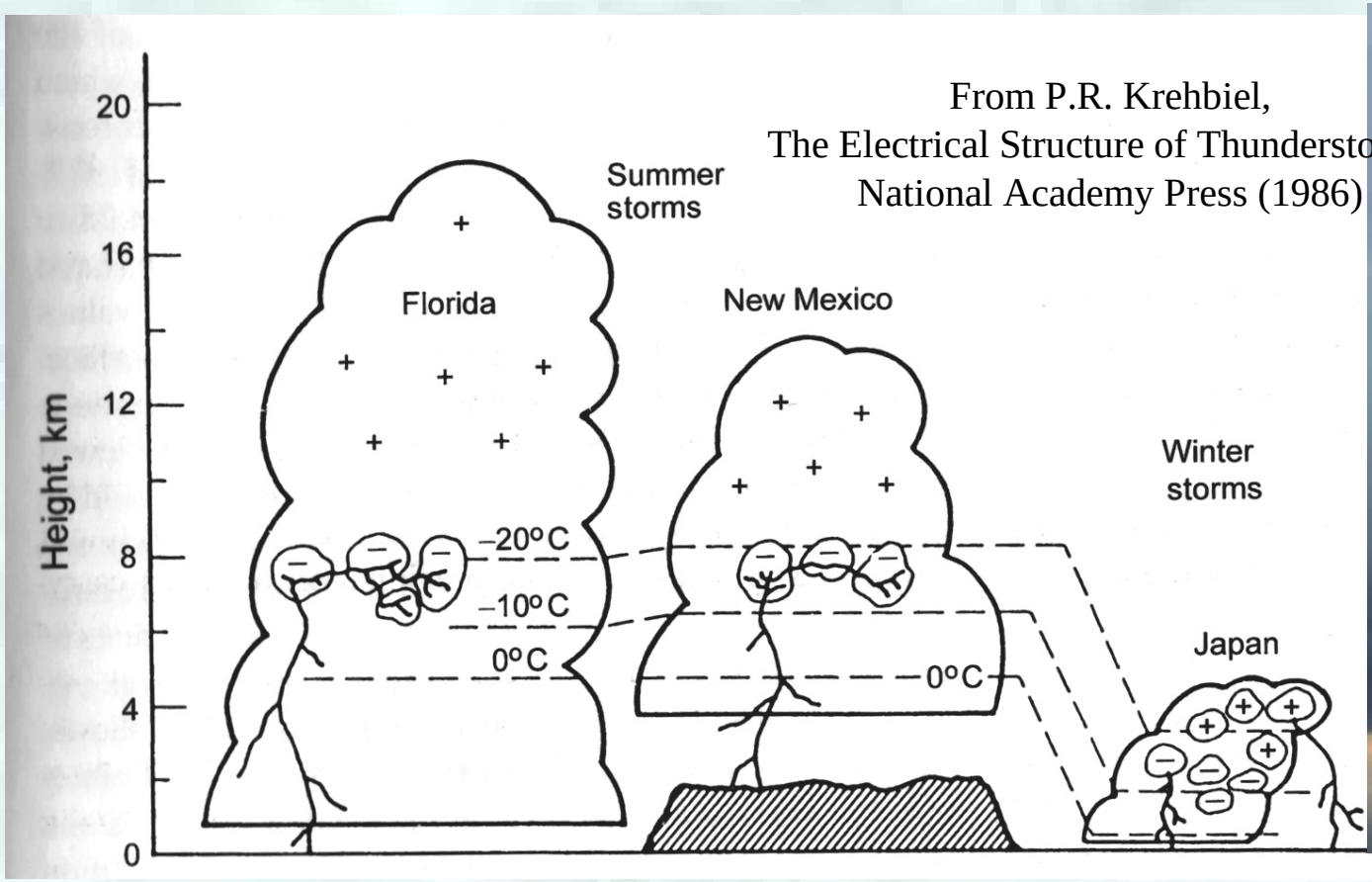




From Marshall and Rust, “Electric Field soundings through thunderstorms”, Journal of Geophysical Research, (1991)

- Water drops & ice crystals carry charge.
- Gravitational settling separates unlike charges.
- Updrafts provide the power to cause many particle collisions that transfer charge

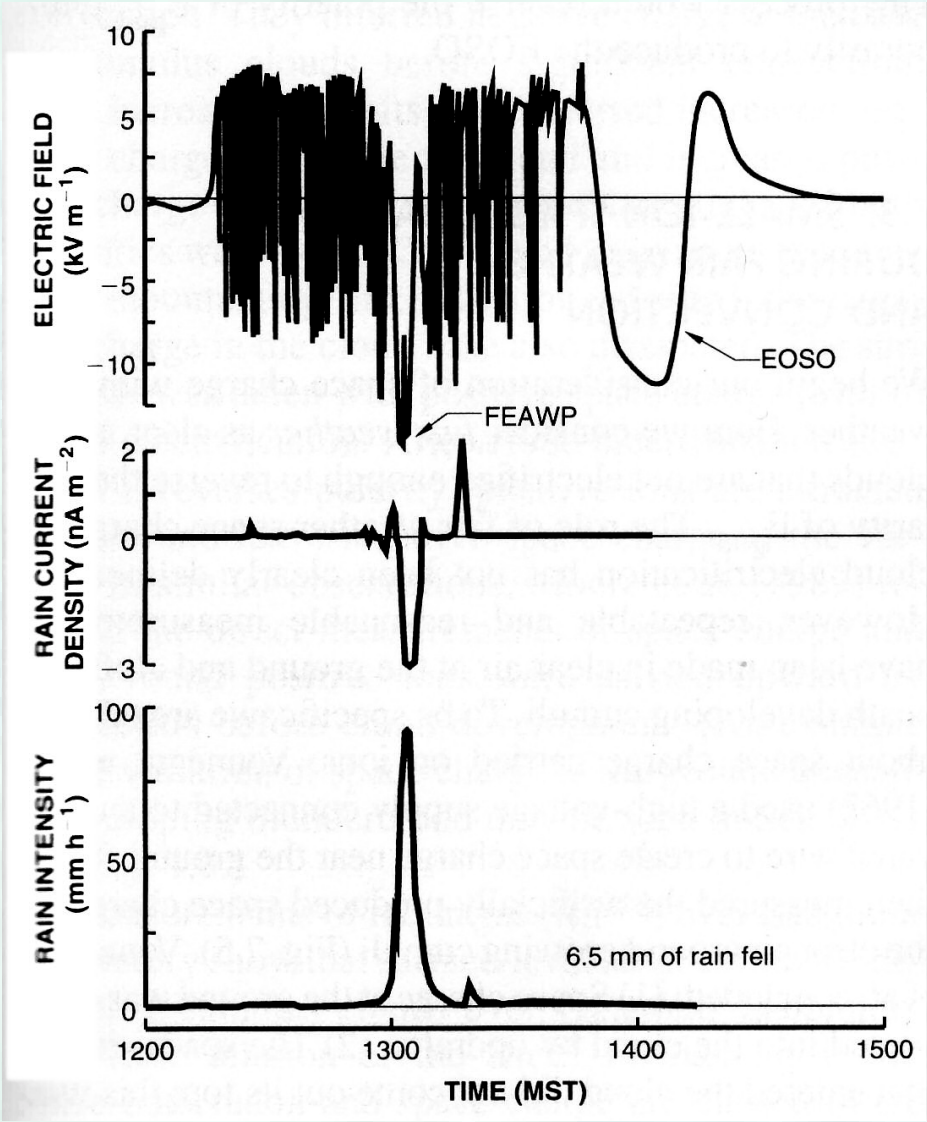
# Evidence for Non-Inductive Charging

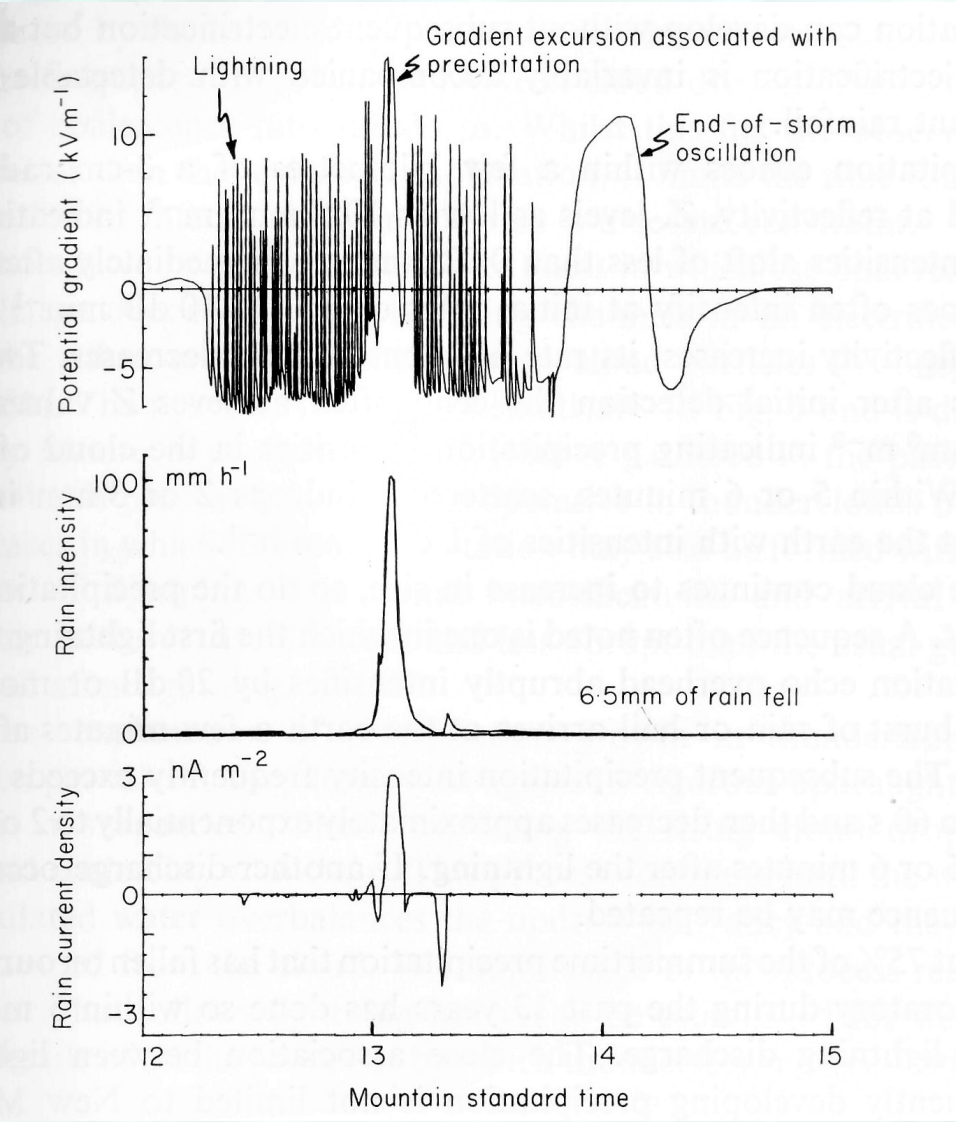
- The negative charge center in storms is always found around the –10C Isotherm.




From P.R. Krehbiel,
The Electrical Structure of Thunderstorms"
National Academy Press (1986)

# Electrical Activity of a Small Mountain Storm




From Moore and Vonnegut, "The Thundercloud" (R.H. Golde, editor) (1977)

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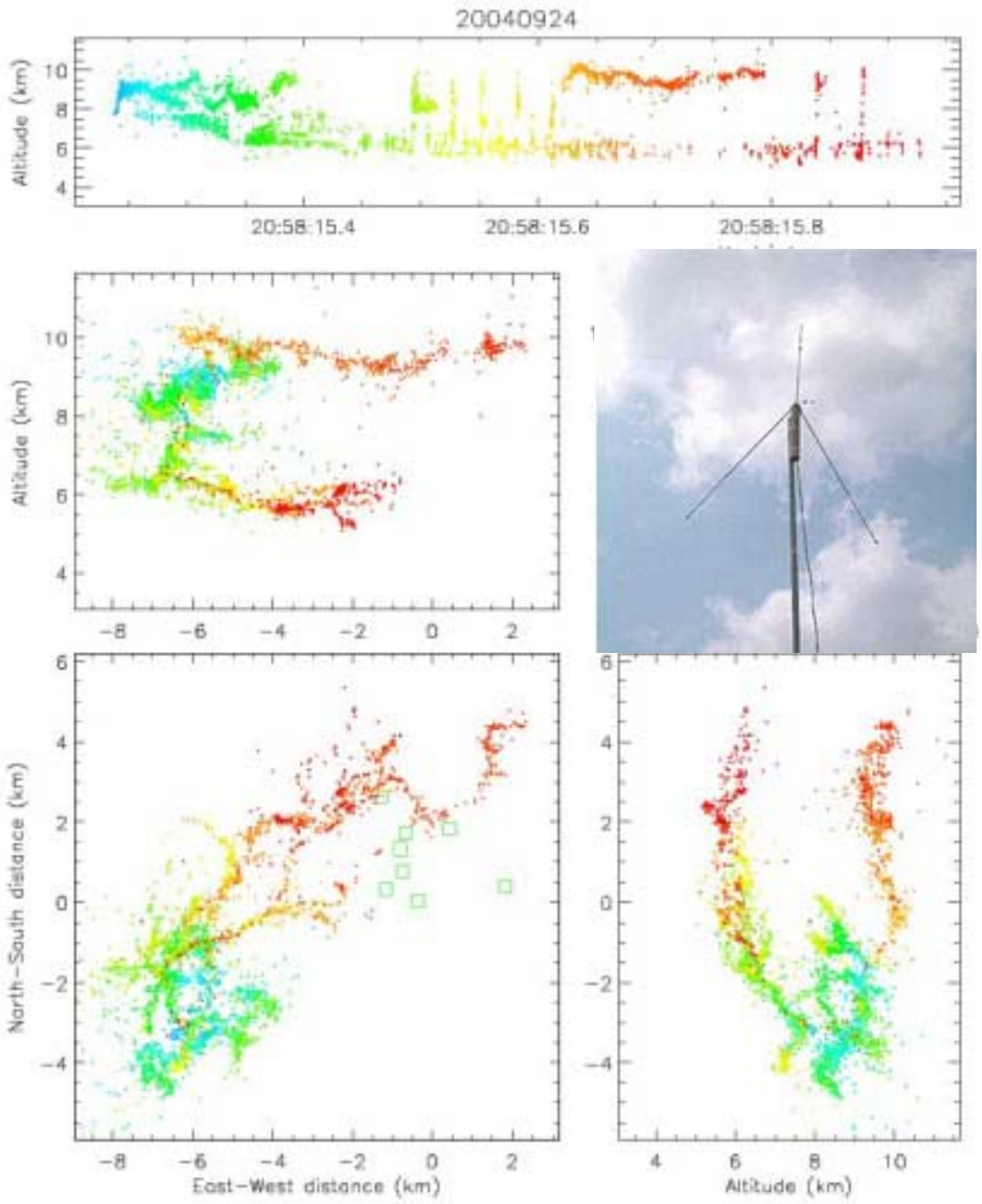
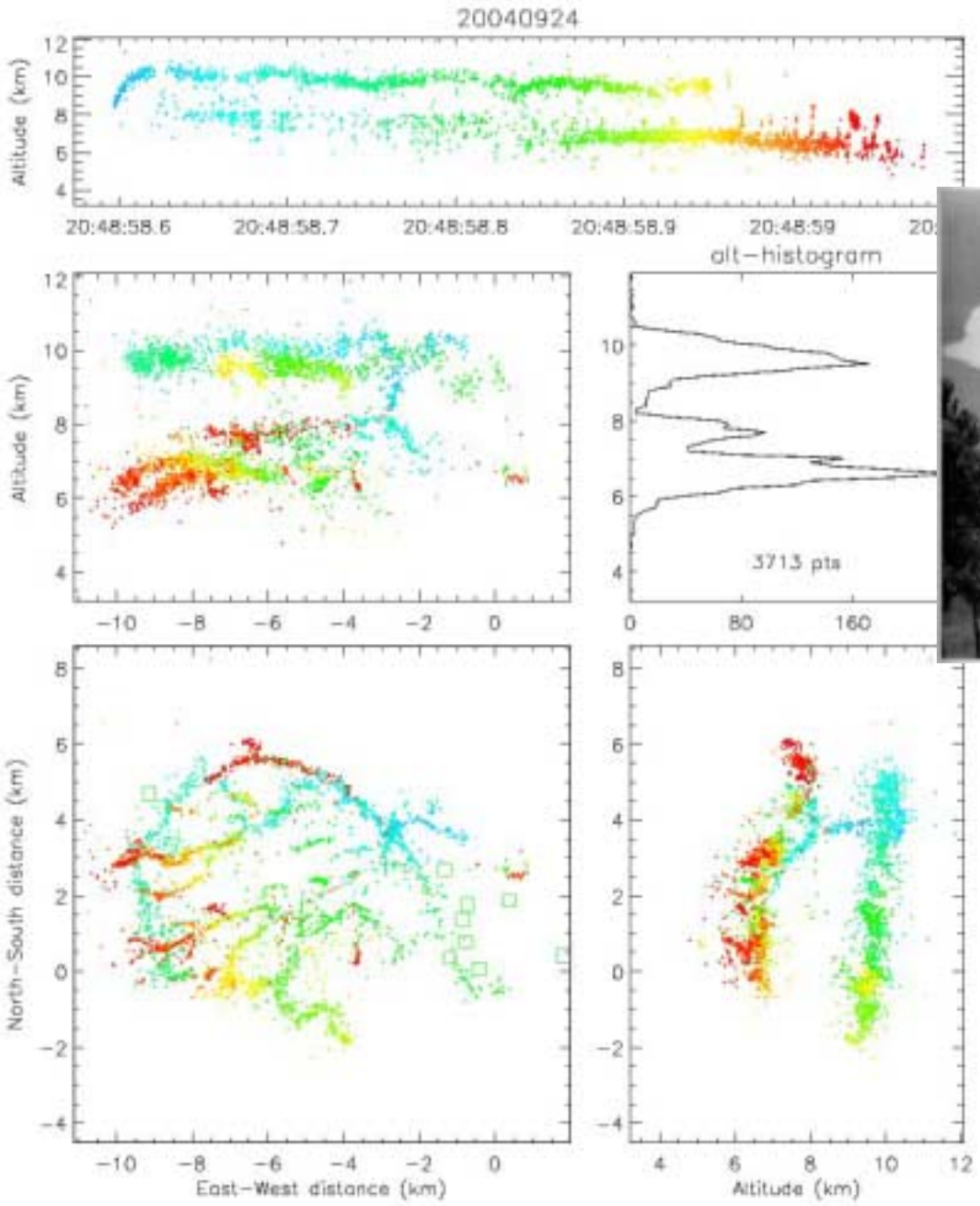
# August 2004 Launch of delta-E Sonde

New Mexico Tech
Lightning Mapping Array (LMA)




- Uses a network of 12 television receivers tuned to 66 MHz.
- Lightning radio pulses are correlated in time between stations.
- Location in sky and emission time are fit and plotted.
- Images intra-cloud (IC) flashes

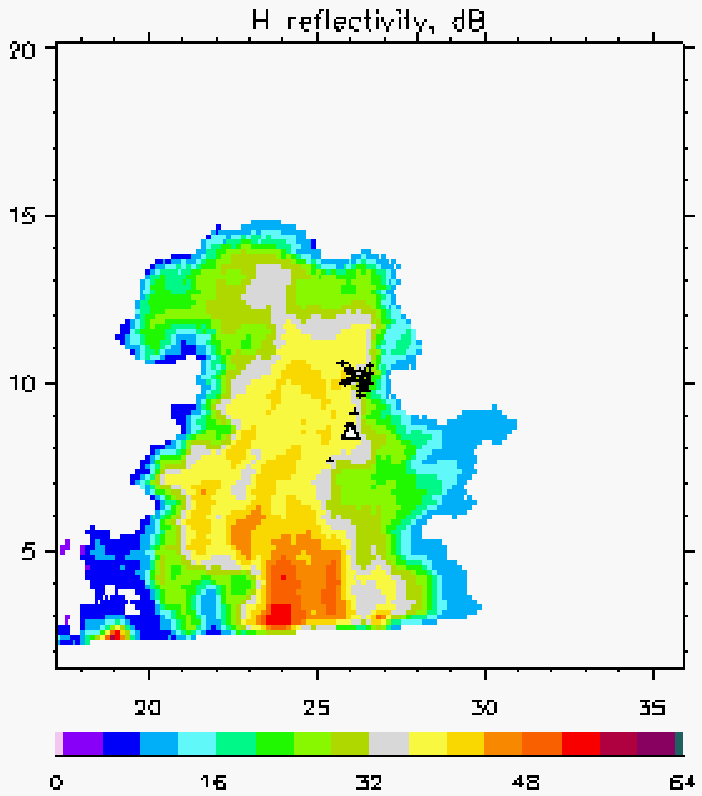
New Mexico Tech
Lightning Mapping Array (LMA)



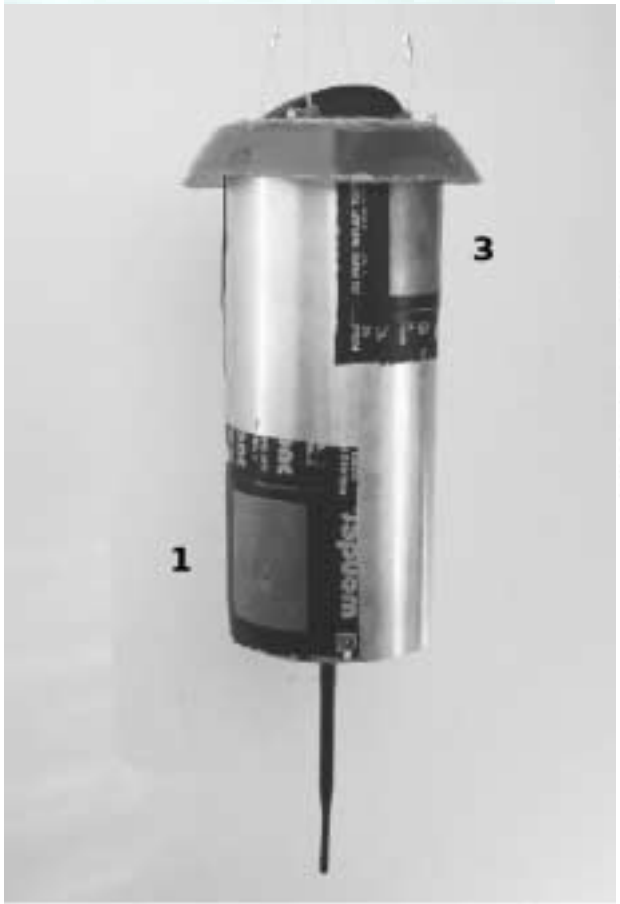


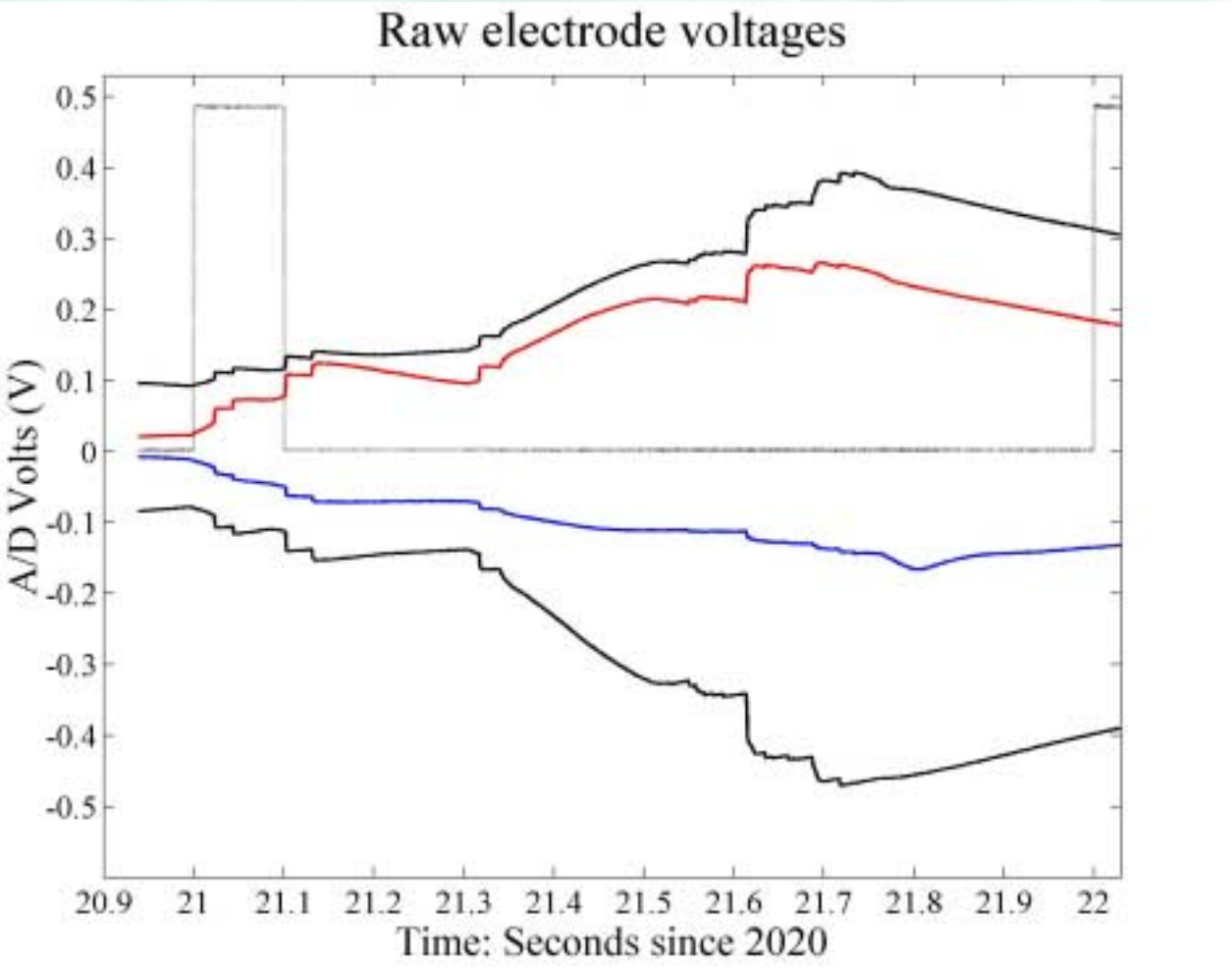
- Lightning initiates in high-field region between charge centers.
- Lightning spreads out horizontally as it drains charge centers.

# Bolt from the blue

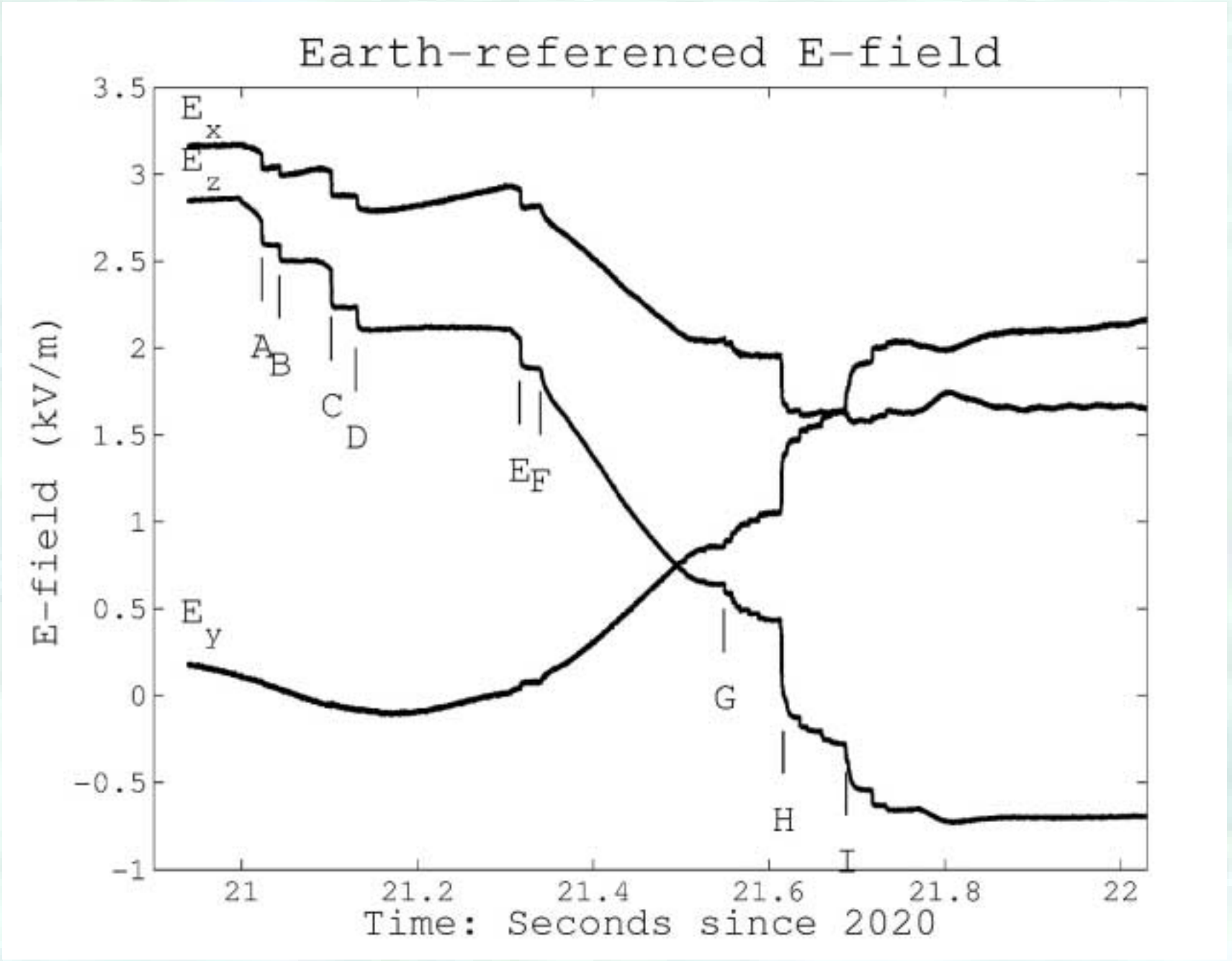



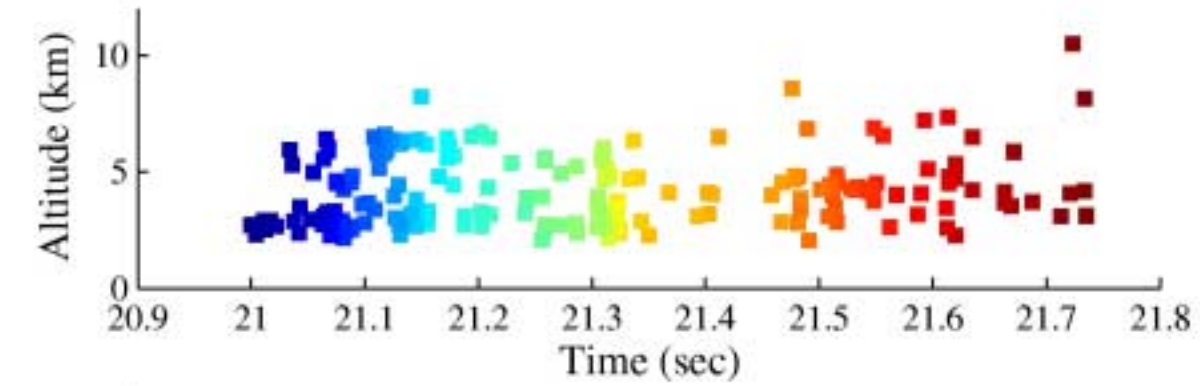

- LMA animation from Ron Thomas, EE Dept, New Mexico Tech

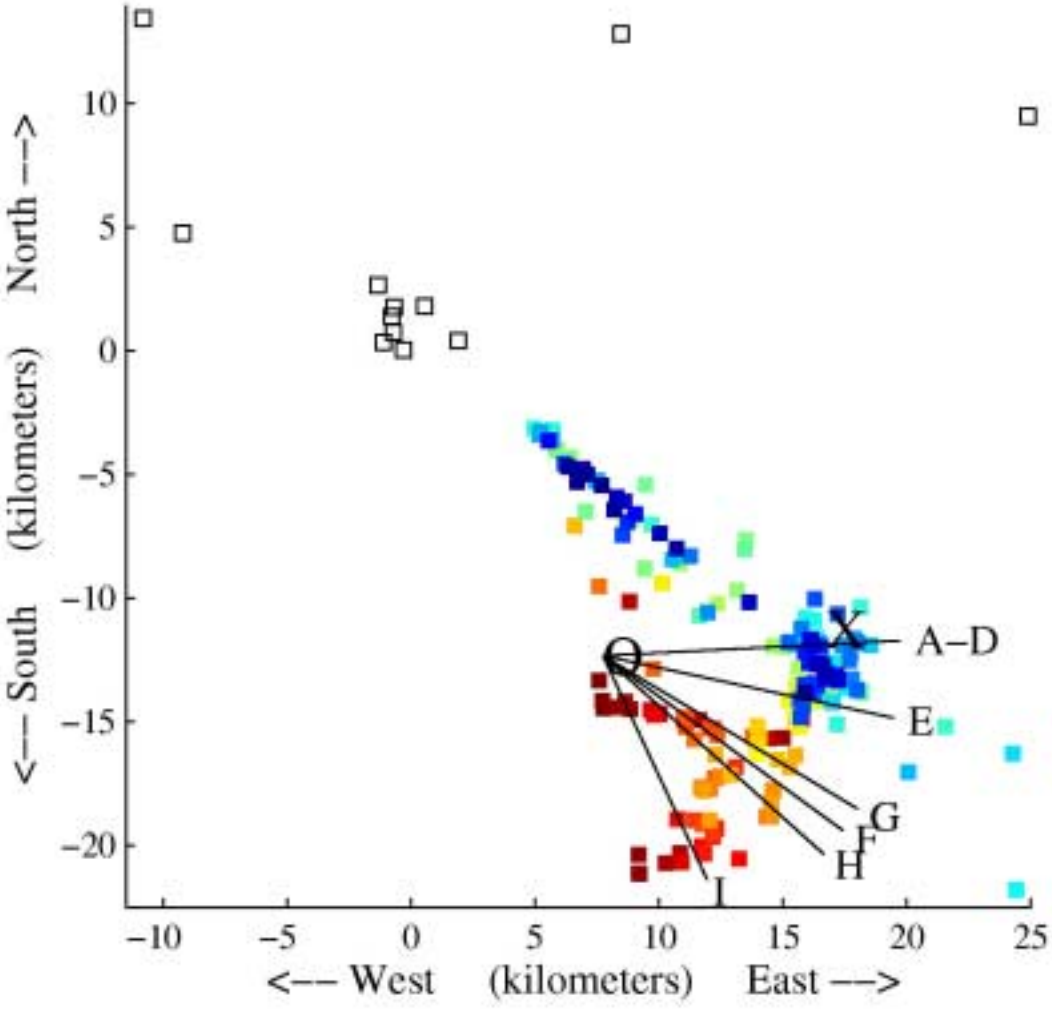



- From Sonnenfeld, Battles, Lu and Winn, J. Geophys. Res., 2006 (submitted)


Earth-referenced E-field
E-field (kV/m)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
E x
E z
E y
A
B
C
D
E F
G
H
I
21
21.2
21.4
21.6
21.8
22
Time: Seconds since 2020




- From Sonnenfeld, Battles, Lu and Winn, J. Geophys. Res., 2006 (submitted)

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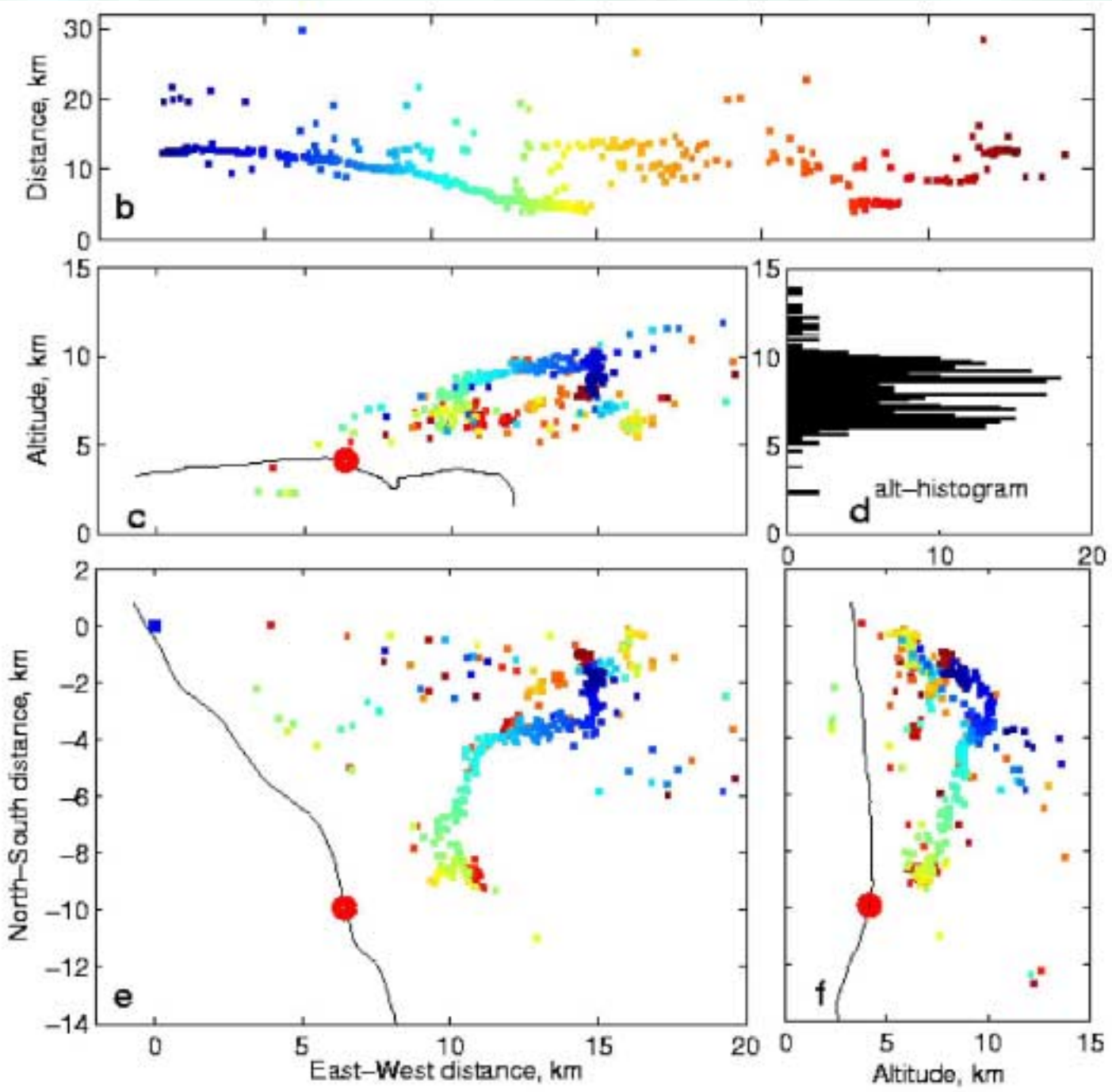

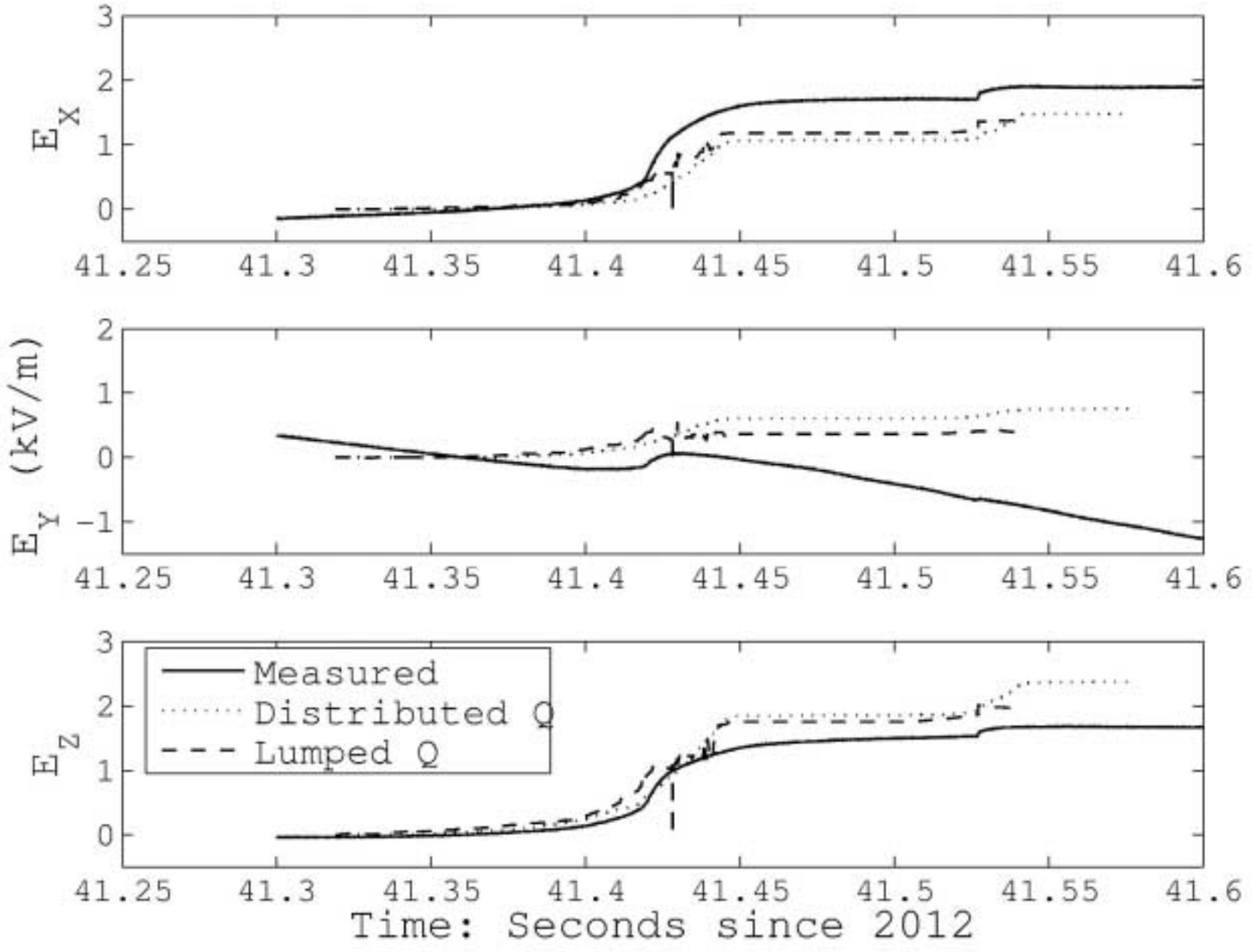
E_X
E_Y (kV/m)
E_Z
Measured
Distributed Q
Lumped Q
41.25
41.3
41.35
41.4
41.45
41.5
41.55
41.6
Time: Seconds since 2012

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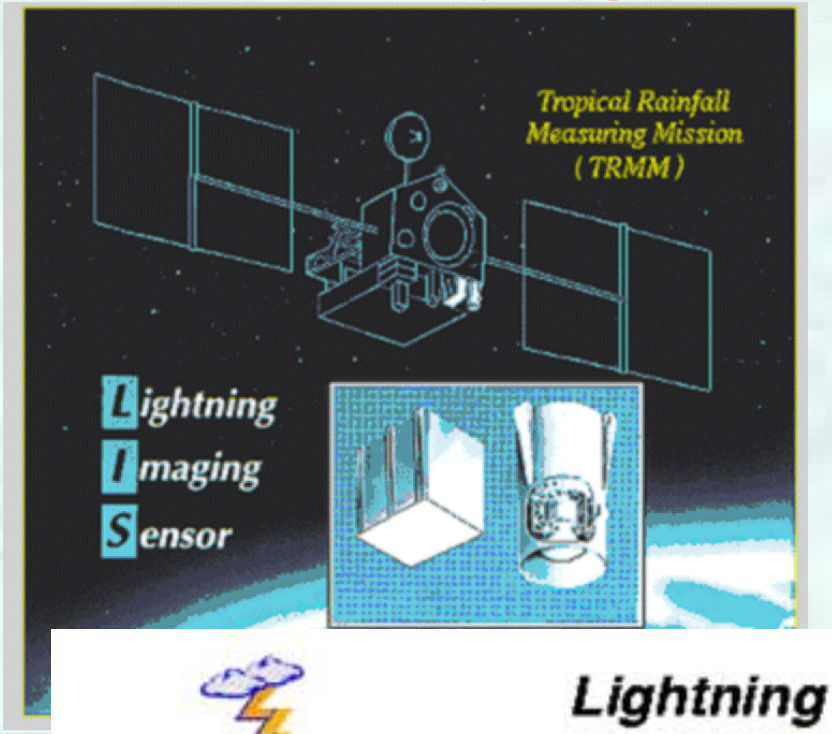
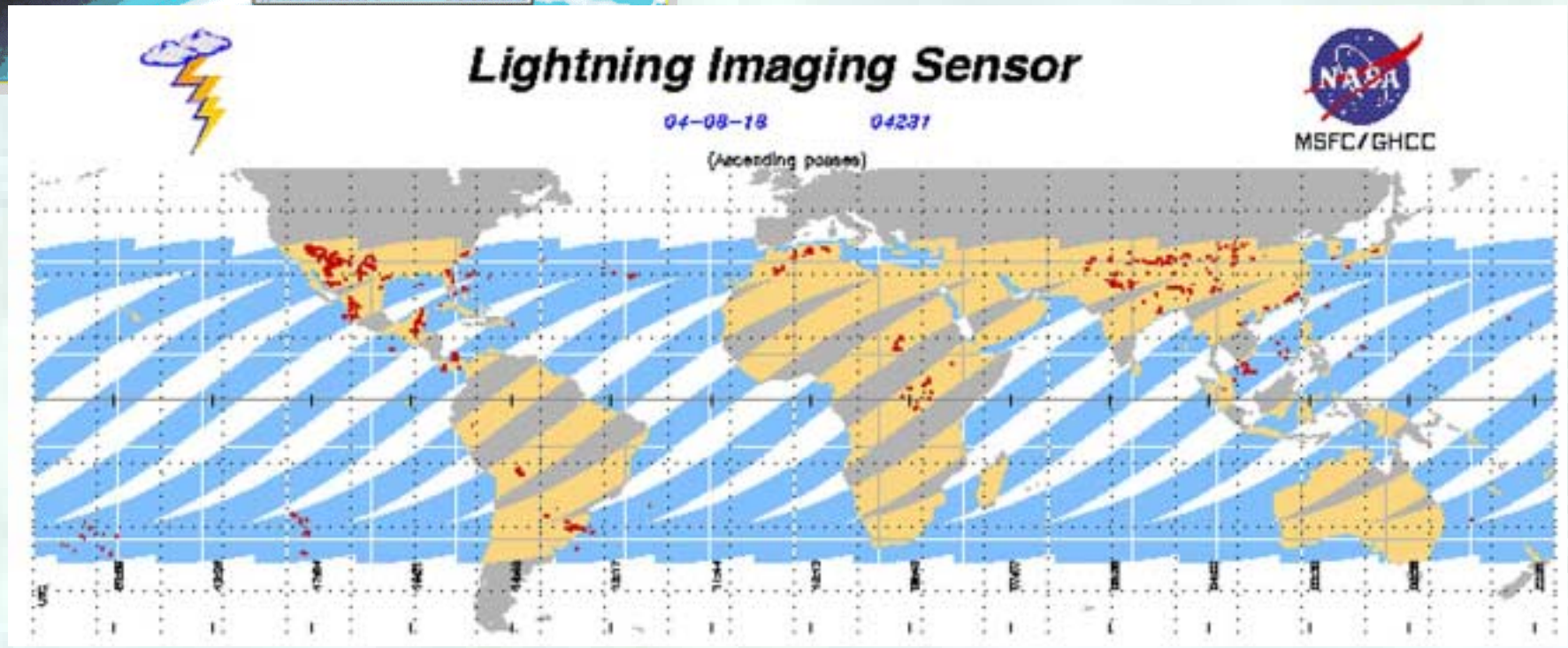
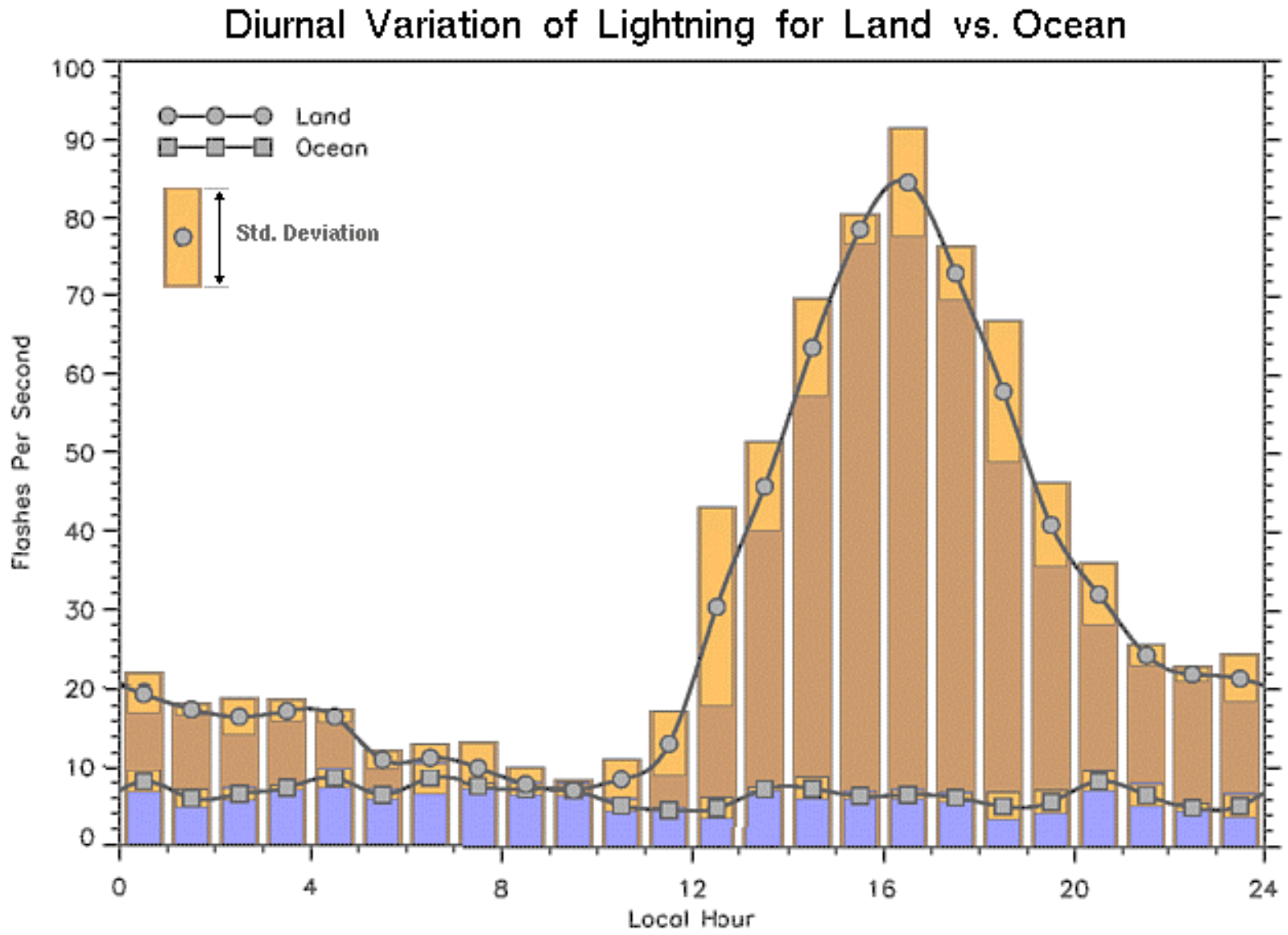
# Lightning Observations from Space




Diurnal Variation of Lightning for Land vs. Ocean
Land
Ocean
Std. Deviation
Floshes Per Second
100
90
80
70
60
50
40
30
20
10
0
0
4
8
12
16
20
24
Local Hour

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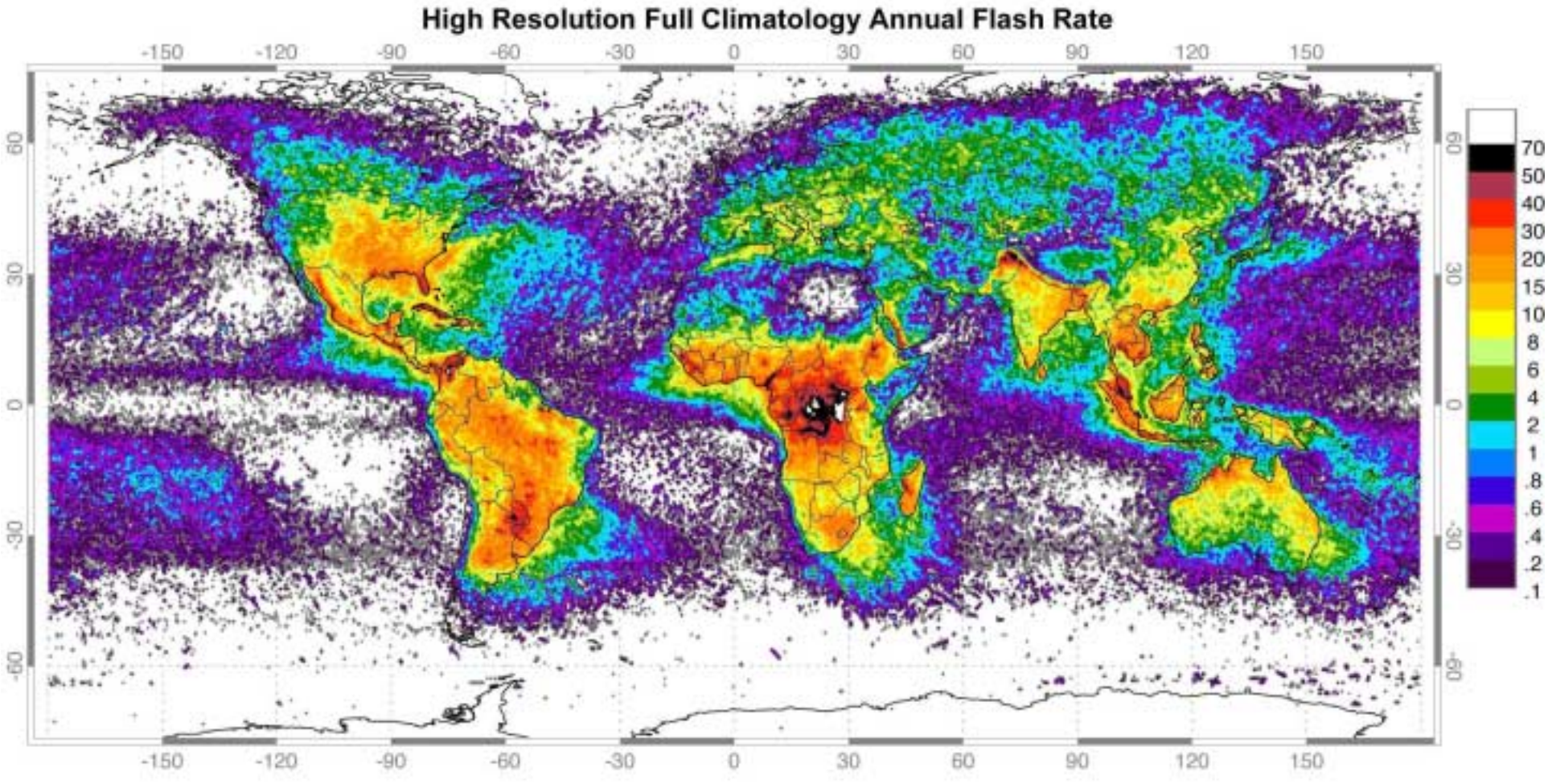

# Summary

- Apparently separate lightning flashes can be attached to the same channel.
- The majority of lightning flashes do not connect to ground. They remain in the clouds.
- Lightning connects to the ground in short steps.
- The “stepped leader” often fails to connect, the successful ones create the flash and bang that we experience.
- If a cloud is charged, we can “trigger” lightning

  (Aircraft do this on their own)

# Summary

- The Earth always has a small “fair-weather” electric field, which is kept charged by lightning.
- By measuring electric field, we can predict that lightning is imminent.
- Most of Earth’s lightning occurs over land, not ocean.
- Most storms have a main negative positive charge near freezing level, with a positive charge at higher altitude.
- Lightning initiates between major charge centers.

# References


- Appetizer
  - [Uman71] “All About Lightning”, Martin A. Uman, Dover Books, (1971)
- Main Meal
  - [Uman01] “The Lightning Discharge”, Martin A. Uman, Dover Books, (2001), 2nd edition.
- Roman Orgy
  - [Rakov03] “Lightning: Physics and Effects” Vladimir Rakov and Martin A. Uman, Cambridge University Press, (2003).

# Unanswered Questions

- What REALLY is the charging mechanism? (Ice/water tribology)
  - Is ice required for lightning?
- What triggers lightning strikes? (Cosmic Rays)
- Does lightning trigger precipitation? (Rain gush)
- How does the charge move in a lightning channel?
- Can a more effective warning or protection system be devised?
- Can lightning be used to predict tornadoes?